DECARBONIZATION OF RURAL SETTLEMENTS: CHARTING A PATHWAY FOR SUSTAINABLE GROWTH IN NAGPUR METROPOLITAN REGION

Project Phase -II Report submitted to
Visvesvaraya National Institute of Technology, Nagpur
in partial fulfillment of the requirements for the award of the degree

Master of Technology
In
Urban Planning

by

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Under the guidance of

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2024-25

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Declaration

I, **Prachi Kothary,** hereby declare that this project titled **"Decarbonizing rural areas: charting a pathway for sustainable growth in Nagpur Metropolitan Region"** is carried out by me in the **Department of Architecture and Planning** of Visvesvaraya National Institute of Technology, Nagpur. The work is original and has not been submitted earlier whole or in part for the award of any degree/diploma at this or any other Institution / University.

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Acknowledgment

would like to extend my heartfelt thanks to my project supervisor, **Dr. Sameer Deshkar**, for his unwavering support, insightful feedback, and patient guidance at every stage of my research. His mentorship not only strengthened the academic depth of this thesis but also encouraged me to refine my critical thinking.

I also extend my appreciation to **Dr. Prem Lal Patel**, Director, VNIT Nagpur, for providing the institutional platform and facilities essential to carry out this research during Project Phase II. Special thanks to the local governing bodies, **Gram**, for their cooperation during field visits and data collection. Their participation enabled the practical grounding of this study.

I wish to acknowledge the invaluable friendship and support of **Ar Karan Thakkar** and **Ar Rudra Lakhera**, whose inputs and discussions helped me navigate many challenges during this work. I also extend heartfelt appreciation to my friends who stood by me throughout—especially during the most demanding phases of this academic journey.

I owe everything to my parents, **Shri Devaang Kothary** and **Smt. Nehal Kothary** , whose unconditional love, support, and sacrifices have made this achievement possible. Finally, I am deeply thankful to my husband, **Tushar Batra**, for his endless patience, emotional strength, and belief in me—especially during moments when I doubted myself.
To every individual who became part of this journey—your presence has mattered, and your contribution is sincerely appreciated.

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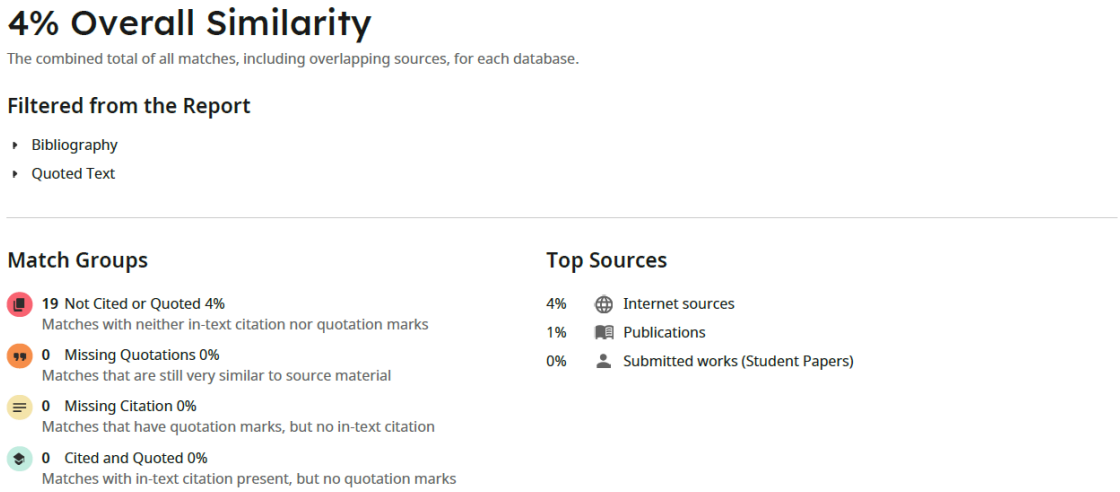
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ABSTRACT

Decarbonizing rural areas is an essential strategy for mitigating climate change and achieving global sustainability targets, particularly in India, where rural regions are integral to the economy and contribute significantly to national carbon emissions. Activities such as agricultural practices, livestock management, stubble burning, and reliance on traditional biomass energy are major sources of emissions in these areas. Despite their critical role, rural emissions often receive less attention than urban sources, leading to exacerbated environmental degradation, public health issues, and socio-economic vulnerabilities.

This study provides a comprehensive examination of the sources of carbon emissions in rural India and evaluates current strategies aimed at reducing these emissions. It explores various methodologies for assessing carbon footprints, including detailed greenhouse gas inventories, and highlights the importance of integrating renewable energy systems, promoting sustainable agricultural practices, and applying circular economy principles. Furthermore, the report underscores the necessity for robust water management systems, efficient waste processing techniques, and energy-smart infrastructure to facilitate a successful low-carbon transition.

Recognizing the unique challenges faced by rural regions—such as data scarcity, implementation variability, and limited community awareness—the study proposes a framework for designing zero-carbon villages. The findings emphasize the significance of fostering community-driven solutions, ensuring policy alignment with local needs, and promoting technological innovation to achieve decarbonization goals. Ultimately, this report positions rural decarbonization not only as a means to align with India's commitment to net-zero emissions by 2070 but also as a transformative pathway that enhances resilience, equity, and environmental sustainability in rural development.

Keywords- Decarbonization, Rural emissions, Sustainable agriculture, Renewable energy, Carbon footprint assessment, Zero-carbon villages

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Chapter -1

INTRODUCTION

1.1 Background Study:

India's trajectory of carbon emissions is increasingly under global scrutiny as the country balances its development priorities with the urgent need for climate action. In recent years, both domestic and international energy dynamics have driven a renewed reliance on coal. Alongside regions like the European Union and other parts of the world, India has seen an uptick in coal consumption, largely as a response to energy security concerns and supply disruptions (International Energy Agency [IEA], 2023) (Frriiedlingstein, 2023). This trend poses significant challenges for climate

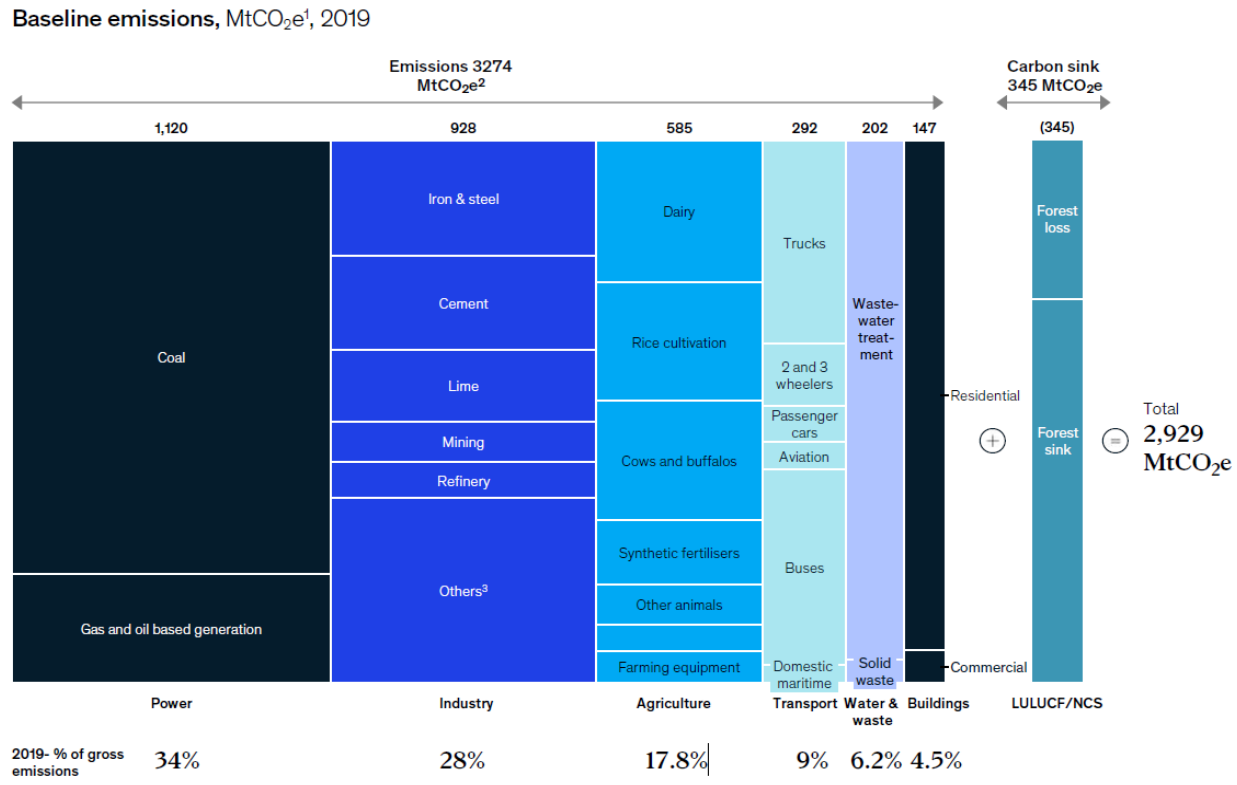


Figure 1.1 India's current carbon emission mix

mitigation efforts, particularly in rapidly urbanizing areas where energy demands are escalating. According to the Global Carbon Project (GCP), the world is nearing a critical climate tipping point. There is now an estimated 50% probability that the average global temperature rise could exceed 1.5°C above pre-industrial levels within the near future if current emission trends persist (Frriedlingstein, et al., 2023). This warning underscores the narrowing window for action and the urgent need to rethink development models, especially in urban centers where infrastructure and policy can either exacerbate or alleviate environmental impacts.

To avoid breaching the 1.5°C threshold, humanity must operate within a strict "carbon budget" the total volume of carbon dioxide that can be released into the atmosphere without triggering dangerous levels of warming (AR6 Synthesis Report: Climate Change 2023. IPCC, 2023)For a populous and rapidly growing nation like India, this means undertaking substantial reforms across sectors including energy production, transportation, construction, and waste management — all of which are integral to urban development (India: Third Biennial Update Report to the UNFCCC. Government of India., 2022)

The Intergovernmental Panel on Climate Change (IPCC) has set ambitious global targets: a 50% reduction in greenhouse gas emissions by 2030 and net-zero emissions by 2050 (AR6 Synthesis Report: Climate Change 2023. IPCC, 2023). Meeting these milestones will require India to rapidly scale up renewable energy deployment, phase out fossil fuel subsidies, and integrate carbon-conscious planning into urban development. Transitioning to sustainable modes of public transportation, promoting green building standards, expanding urban green spaces, and investing in carbon capture and storage technologies are key strategies that must be adopted across cities and metropolitan regions (India Energy Outlook 2021. Government of India, 2021).

Urban planning will play a pivotal role in shaping India's climate future. Cities are not only the largest contributors to carbon emissions but also offer the greatest opportunities for mitigation. As such, coordinated efforts between national policies and local governance structures will be critical in aligning urban growth with climate commitments (World Cities Report 2020: The Value of Sustainable Urbanization. United Nations Human Settlements Programme., 2020) Through strategic planning and technological innovation, Indian cities can transform from emission hotspots into engines of low-carbon development, setting a precedent for sustainable urbanization globally.

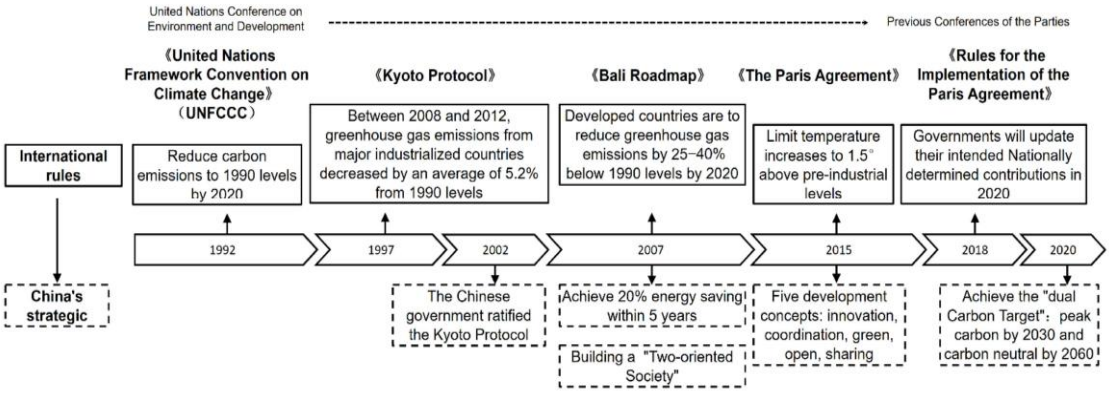

United Nations Conference on Environment and Development
Previous Conferences of the Parties
《United Nations Framework Convention on Climate Change》（UNFCCC）
《Kyoto Protocol》
《Bali Roadmap》
《The Paris Agreement》
《Rules for the Implementation of the Paris Agreement》
International rules
Reduce carbon emissions to 1990 levels by 2020
Between 2008 and 2012, greenhouse gas emissions from major industrialized countries decreased by an average of 5.2% from 1990 levels
Developed countries are to reduce greenhouse gas emissions by 25–40% below 1990 levels by 2020
Limit temperature increases to 1.5° above pre-industrial levels
Governments will update their intended Nationally determined contributions in 2020
1992
1997
2002
2007
2015
2018
2020
China's strategic
The Chinese government ratified the Kyoto Protocol
Achieve 20% energy saving within 5 years
Building a "Two-oriented Society"
Five development concepts: innovation, coordination, green, open, sharing
Achieve the "dual Carbon Target": peak carbon by 2030 and carbon neutral by 2060

Figure 1.2 Evolution of International Rules and Strategies

1.1.1 Rural Emission and their significance

India's carbon emission landscape is often viewed through an urban lens, primarily focusing on cities as hubs of industrial activity, vehicular congestion, and high energy consumption. While urban areas undeniably contribute a significant share of the country's greenhouse gas emissions, this narrow focus overlooks a critical piece of the puzzle — the growing environmental footprint of rural India (Ghosh, 2023).

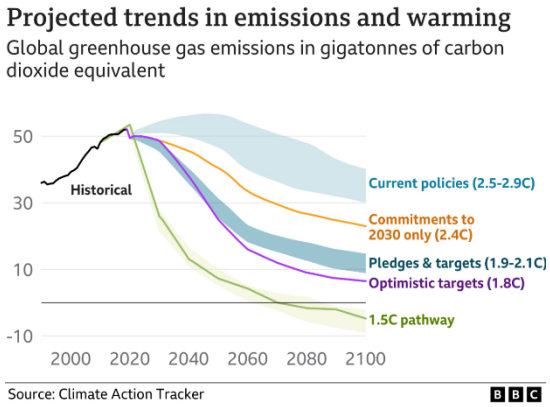


Figure 1.3 Projected trends in emission and warning

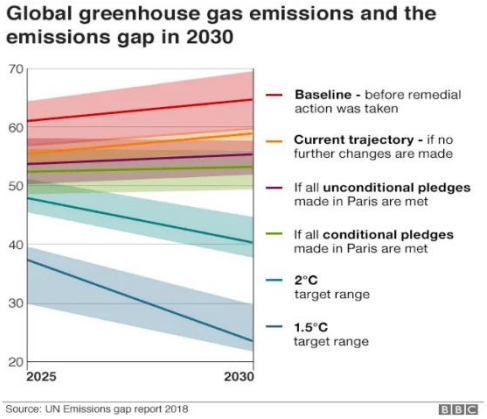


Figure 1.3 Global greenhouse gas emissions and the emissions gap in 2030

Air pollution in India is commonly framed because of urbanization, with attention centered on traffic emissions, construction dust, and industrial output. However, many rural regions face equally severe — though less visible — pollution challenges. The widespread perception of rural India as pristine and unpolluted is increasingly misleading. In reality, numerous rural communities are affected by environmental degradation stemming from both anthropogenic activities and natural sources, contributing substantially to the nation's overall carbon emissions and deteriorating air quality (Central Pollution Control Board (CPCB), 2022)

One notable example is the operation of traditional brick kilns, particularly in states like Rajasthan. These rudimentary kilns are widely used in rural areas due to their low cost and minimal regulatory oversight. However, they emit large quantities of particulate matter, carbon monoxide, black carbon, and other greenhouse gases. The pollutants not only affect local air quality but also contribute to regional climate change and public health issues, such as respiratory illnesses and cardiovascular conditions (Baidya, 2022). Despite their environmental impact, these sources often escape the attention of mainstream pollution control strategies, which tend to prioritize urban emission sources.

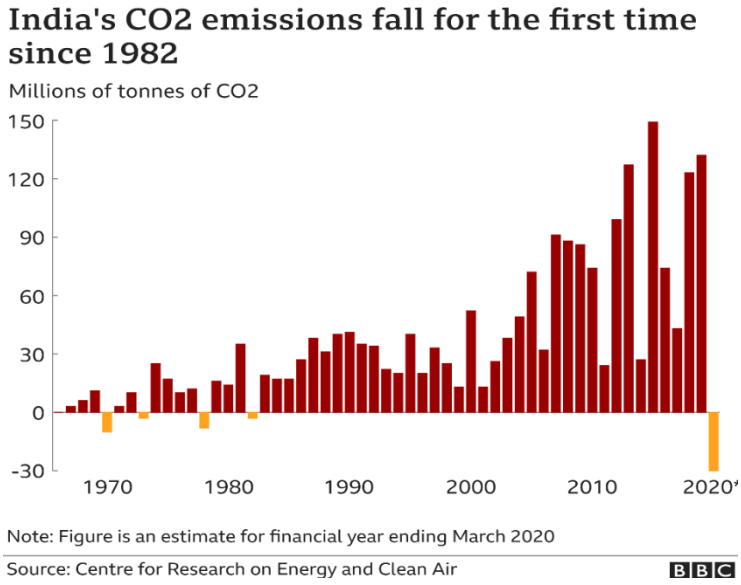


Figure 1.4 India's CO2 Emissions

The lack of stringent regulation and clean technology adoption in rural industrial practices exacerbates the carbon footprint of these regions. Biomass burning, unregulated use of diesel generators, and inefficient agricultural practices — such as residue burning — also add to the rural pollution burden. These emissions cumulatively undermine national efforts to curb climate change and meet international commitments such as the Paris Agreement (Ministry of Environment, Forest and Climate Change (MoEFCC), 2023).

From an urban planning and policy perspective, addressing India's carbon emission scenario requires a more holistic and integrated approach that includes both urban and rural ecosystems. Rural areas must be recognized not only as victims of climate change but also as contributors whose practices can significantly influence emission trajectories. Incorporating rural emissions into national climate planning can help in crafting more effective, inclusive, and equitable solutions (NITI Aayog, 2023).

For meaningful progress, targeted interventions are needed in rural regions: modernizing brick kiln technology, promoting clean cooking fuels, adopting sustainable agricultural practices, and enforcing decentralized renewable energy solutions. Urban planning must extend its reach beyond city boundaries, fostering rural-urban partnerships that enhance environmental resilience and ensure that climate action is both comprehensive and just (TERI, 2022).

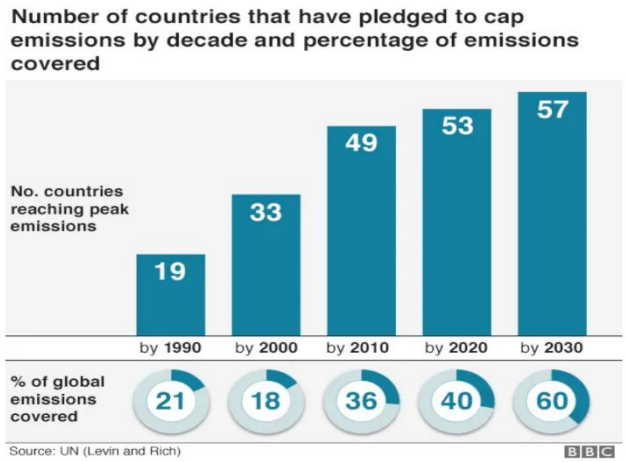


Figure 1.6 Global Emissions of overall countries

India's carbon emission and air pollution profile is deeply intertwined with public health, yet much of the national focus remains skewed toward urban centers. While cities receive considerable attention due to visible pollution from traffic, construction, and industry, rural areas face equally — and in some cases more severe — pollution burdens, with significant consequences for human health and climate

targets (State of Global Air, 2023).

Air pollution is a leading cause of premature mortality in India, claiming an estimated 1.05 million lives annually. Surprisingly, about 69% of these deaths occur in rural areas, challenging the common misconception that pollution is predominantly an urban crisis. Fine particulate matter (PM2.5) and ground-level ozone — two of the most harmful air pollutants — are often recorded at higher concentrations in rural regions than in some urban zones. These pollutants are linked to chronic respiratory conditions, cardiovascular diseases, and developmental impacts in children (Health Effects Institute (HEI), 2023).

A major contributor to rural air pollution is stubble burning, particularly in the agriculturally intensive Indo-Gangetic Plains. Farmers often resort to burning crop residues — notably rice stubble — due to the high cost and limited availability of sustainable disposal alternatives. On average, each acre of rice cultivation yields about 23 quintals of stubble, a significant portion of which is set alight. This practice alone contributes roughly 7% of India's total PM2.5 emissions, leading to seasonal spikes in air pollution that affect both rural populations and urban centers downwind, including Delhi (Venkataraman, 2021).

Despite these severe impacts, rural areas remain largely excluded from national air quality monitoring and policy frameworks. The National Clean Air Programme (NCAP), launched to reduce particulate pollution by 20–30% by 2024, has been heavily focused on urban regions. It offers little strategic emphasis on rural emission sources or mitigation measures tailored to agrarian contexts (Ministry of Environment, Forest and Climate Change (MoEFCC), 2023).

This urban-centric approach is further reflected in the country's air monitoring infrastructure. Of the 804 operational air quality monitoring stations across India, only 26 are located in rural areas, with the vast majority concentrated in major cities. Outside of Punjab, real-time monitoring in rural areas is almost non-existent, making it difficult to assess pollution trends or design effective interventions (Central Pollution Control Board (CPCB), 2022).

From an urban planning perspective, this disconnect represents a critical policy gap. The health and environmental implications of rural pollution have a direct bearing on national sustainability goals and urban air quality, particularly given the transboundary nature of air pollutants. Incorporating rural emissions into urban planning and national climate strategies is not just equitable — it is essential for achieving comprehensive environmental governance (TERI, 2022).

To address this, urban and regional planning must evolve to include integrated rural-urban air quality management, expansion of monitoring networks into underrepresented areas, and investment in cleaner agricultural practices. Solutions such as mechanized stubble management, bioenergy generation from crop residues, and cleaner cooking technologies can significantly reduce rural emissions if supported by appropriate infrastructure and policy incentives (NITI

Aayog, 2023).

In conclusion, India's carbon emission scenario is a complex mosaic of urban and rural sources. A truly effective climate and air quality strategy must bridge the rural-urban divide, leveraging both technological innovation and community-based solutions to create a healthier, low-carbon future for all.

1.1.2 Pollution linkages between Rural and Urban Areas {e.g Delhi Case Study}

Air pollution in India's capital, Delhi, is not solely an urban-generated problem—it is a multifaceted issue shaped by significant environmental interactions with neighboring rural regions. This rural-urban dynamic is particularly evident during specific seasons, when pollutant flows from surrounding agricultural areas intensify the already critical air quality situation in the city .

Figure 1.7 Punjab's stubble burnin g creating SMOG

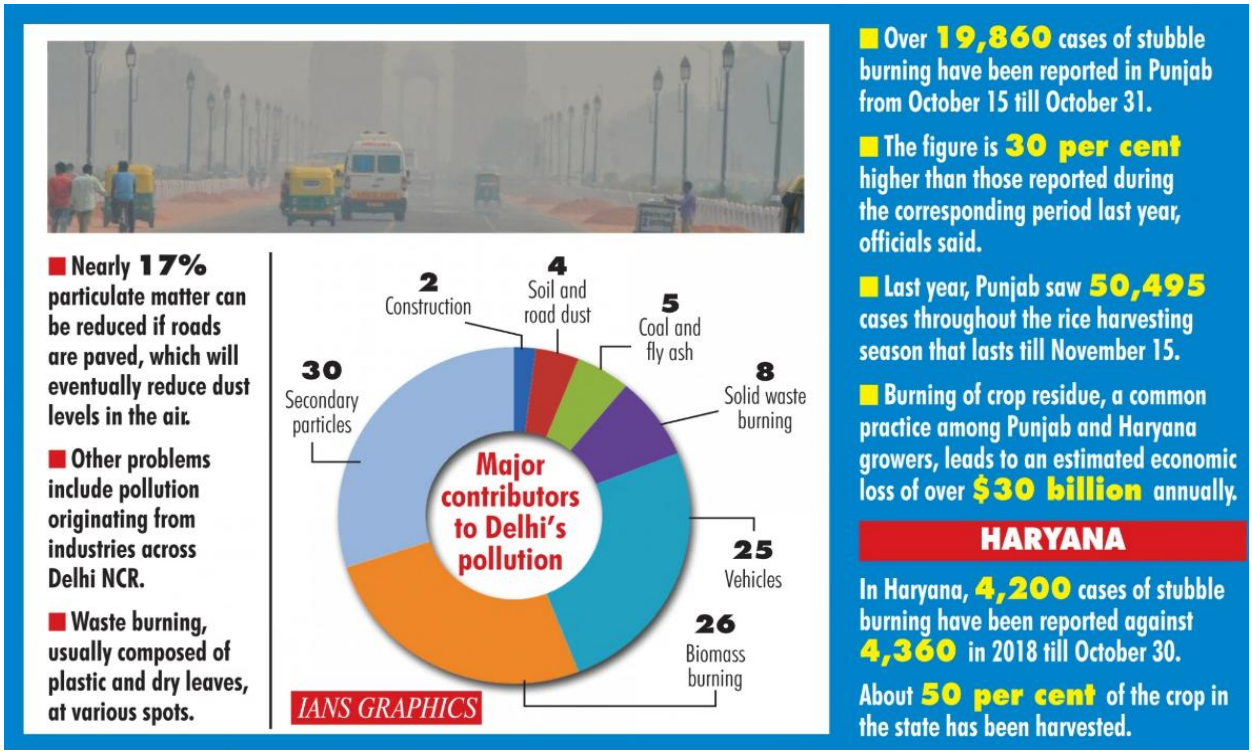

Nearly 17% particulate matter can be reduced if roads are paved, which will eventually reduce dust levels in the air.
Other problems include pollution originating from industries across Delhi NCR.
Waste burning, usually composed of plastic and dry leaves, at various spots.
2 Construction
4 Soil and road dust
5 Coal and fly ash
8 Solid waste burning
25 Vehicles
26 Biomass burning
30 Secondary particles
Major contributors to Delhi's pollution
IANS GRAPHICS
Over 19,860 cases of stubble burning have been reported in Punjab from October 15 till October 31.
The figure is 30 per cent higher than those reported during the corresponding period last year, officials said.
Last year, Punjab saw 50,495 cases throughout the rice harvesting season that lasts till November 15.
Burning of crop residue, a common practice among Punjab and Haryana growers, leads to an estimated economic loss of over $30 billion annually.
HARYANA
In Haryana, 4,200 cases of stubble burning have been reported against 4,360 in 2018 till October 30.
About 50 per cent of the crop in the state has been harvested.

Figure 1.8 Delhi's Pollution Scenario

Stubble Burning and Cross-Border Airflows

A key contributor to seasonal spikes in air pollution is the widespread practice of crop residue burning, especially following the rice harvest in the northern states of Punjab, Haryana, and Uttar Pradesh. Farmers in these regions often burn leftover paddy straw to prepare their fields for the

next planting season, releasing enormous volumes of smoke, carbon dioxide, methane, and fine particulate matter (PM2.5) into the atmosphere. Due to prevailing wind patterns in the autumn and early winter months, these pollutants are carried over long distances, blanketing Delhi in a thick haze and significantly degrading its air quality (Venkataraman, 2021). (Refer fig No. 1.8)

Dust Emissions from Rural Infrastructure and Agriculture

Rural areas surrounding Delhi are also responsible for considerable dust pollution. Unpaved roads, open fields, and ongoing agricultural activities generate vast amounts of coarse particles that are easily lifted into the air, especially in dry conditions. The lack of vegetation cover and soil stabilization in these areas leads to frequent soil erosion, further compounding particulate pollution. This rural-origin dust is frequently transported into the capital region, contributing to the persistent high levels of airborne particles detected by urban air monitoring systems (TERI, 2022). (Refer fig No. 1.8)

Biomass Burning in Rural Households

Another significant yet often overlooked source of air pollution linked to rural lifestyles is the combustion of biomass for household energy needs. In many villages near Delhi, families rely on firewood, cow dung, and crop residues for cooking and heating due to limited access to clean energy alternatives. This results in continuous low-level emissions of smoke and harmful gases, which are not confined to village boundaries but can drift toward urban areas and exacerbate the city's pollution levels, particularly during periods of atmospheric stagnation in winter .

Scientific Evidence of Rural-Urban Pollution Interlinkages

Research conducted by the Council on Energy, Environment and Water (CEEW) has quantified the extent of external pollution influences on Delhi's air quality. The study found that approximately 64% of Delhi's winter pollution originates from outside the city's boundaries. The major contributors include transport emissions, regional dust storms, and rural biomass burning, demonstrating how urban pollution cannot be addressed effectively without accounting for its rural sources (CEEW, 2022).

Implications for Urban Planning and Policy

This rural-urban pollution nexus presents a significant challenge for planners and policymakers. Traditional urban air quality management strategies, which focus on internal city emissions, fail

to address the broader regional ecosystem that impacts metropolitan air quality. Therefore, an integrated approach is crucial—one that considers rural emissions in regional air management plans and supports collaborative interventions across state and administrative boundaries (Central Pollution Control Board (CPCB), 2022).

Policy solutions might include promoting sustainable agricultural practices, such as mechanical stubble management and crop diversification, incentivizing rural households to adopt clean cooking fuels and technologies, and investing in infrastructure development like road paving and dust control measures in peri-urban areas. Real-time air quality monitoring networks must also be expanded to rural zones to capture accurate data and inform policy responses (Ministry of Environment, Forest and Climate Change (MoEFCC), 2023).

In conclusion, understanding and mitigating air pollution in cities like Delhi requires a regional systems approach. The interconnected nature of rural and urban pollution sources calls for joint governance models, shared resource planning, and holistic environmental strategies that bridge the urban-rural divide.

1.2 Importance of Rural Decarbonisation :

Rural pollution in India remains a critically under-recognized environmental and public health challenge, despite growing empirical evidence that air quality in many rural regions is deteriorating due to a combination of anthropogenic and natural sources. Historically, pollution has been predominantly viewed as an urban issue, associated with vehicular emissions, industrial clusters, and infrastructure expansion. However, recent studies have revealed that rural areas often experience pollution levels comparable to, or in some cases exceeding, those in urban regions—particularly in terms of fine particulate matter ($PM_{2.5}$) and ground-level ozone (State of Global Air, 2020). The decentralization of industries, especially brick kilns, has contributed significantly to this trend, as these high-emission industries relocate from tightly regulated urban cores to loosely governed rural and peri-urban zones. For instance, traditional brick kilns common in rural Rajasthan emit substantial quantities of particulate matter and black carbon, thereby degrading local air quality and exacerbating greenhouse gas emissions (Guttikunda & Calori, 2013). (Refer fig No. 1.9)

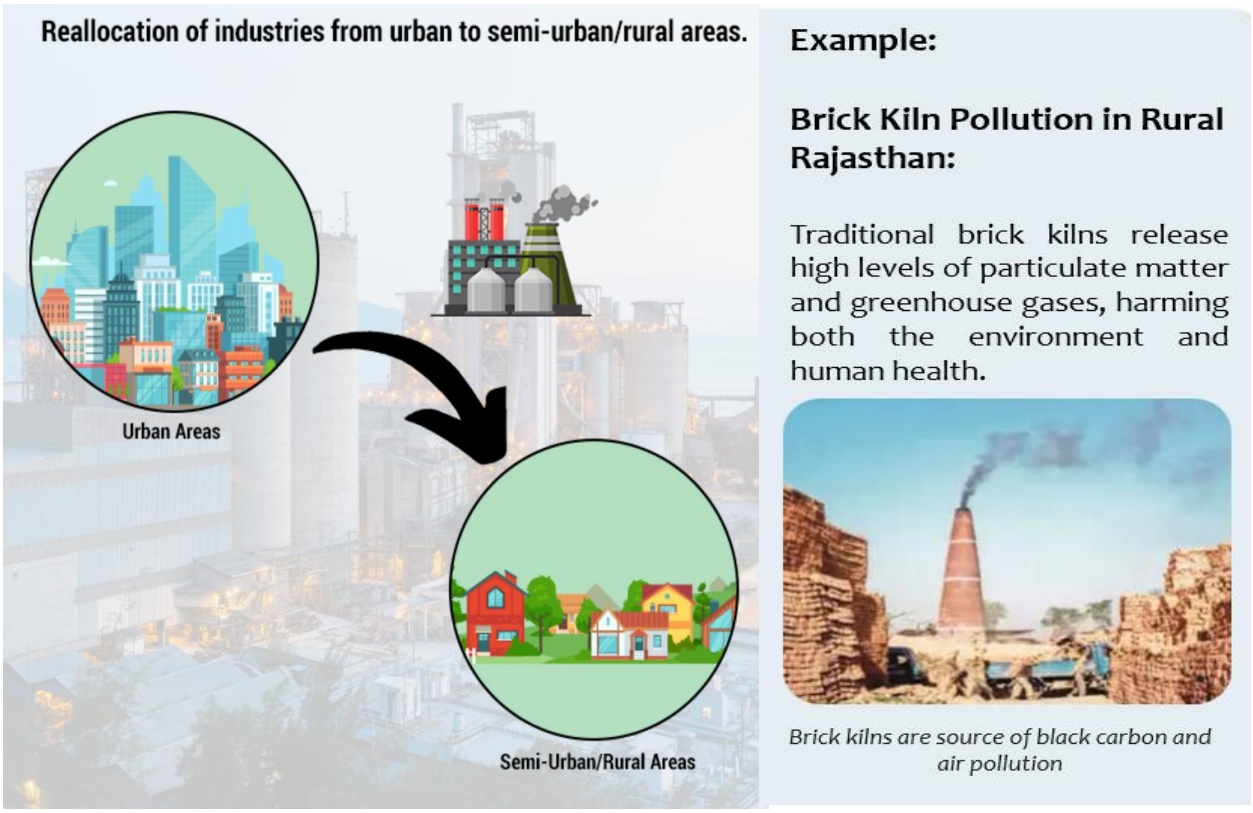

Reallocation of industries from urban to semi-urban/rural areas.
Urban Areas
Semi-Urban/Rural Areas
Example:
Brick Kiln Pollution in Rural Rajasthan:
Traditional brick kilns release high levels of particulate matter and greenhouse gases, harming both the environment and human health.
Brick kilns are source of black carbon and air pollution

Figure 1.9 Relocation of industries from urban to semi-urban and Brick Kilns in Rajasthan

Agricultural practices further intensify seasonal air pollution in rural areas, particularly in the Indo-Gangetic Plains. Paddy cultivation alone generates nearly 23 quintals of crop residue per acre, a large portion of which is openly burned, contributing to approximately 7% of India's annual $PM_{2.5}$ emissions (TERI, 2019). The implications for public health are severe. According to the Institute for Health Metrics and Evaluation (IHME, 2020), air pollution accounts for roughly 1.05 million premature deaths each year in India, with an overwhelming 69% of these occurring in rural regions.

Yet, rural areas remain grossly underserved in terms of environmental monitoring infrastructure. As of the latest data under the National Clean Air Programme (NCAP), only 26 out of 804 monitoring stations are situated in rural areas, creating a significant data vacuum that hinders effective intervention (CPCB, 2021).

In addition to air quality issues, rural regions are burdened by substantial greenhouse gas emissions originating from both direct and indirect sources. Long-range transboundary pollutants from wildfires, forest clearing, desert dust, and volcanic eruptions can travel across borders, worsening air quality in remote rural areas (UNEP, 2020). Locally, fossil fuel combustion for cooking, agricultural machinery, and emerging rural industries contribute heavily to CO_2 and black carbon emissions (IEA, 2021). One of the most potent rural emission sources is the widespread use of nitrogen-based fertilizers such as urea and ammonium nitrate, which emit nitrous oxide (N_2O)—a greenhouse gas with nearly 300 times the global warming potential of CO_2 over a 100-year period (IPCC, 2021). This is compounded by improper application practices and the absence of precision agriculture, particularly in water-intensive crops like rice (FAO, 2019). Pesticides also release volatile organic compounds (VOCs), contributing to secondary air pollutant formation and climate impact (Lal, 2004).

Equally concerning are emissions from rural waste disposal practices. In the absence of formal solid waste management systems, the open dumping and burning of biodegradable and plastic waste is widespread, emitting a mixture of CO_2, CH_4, black carbon, and other toxic pollutants (CPCB, 2020). Anaerobic conditions in unmanaged dumps generate methane, while livestock waste, when not managed through technologies like biogas digesters, adds further CH_4 emissions to the rural carbon footprint (MNRE, 2021). Other environmental pressures such as dust from unpaved roads, rural construction activities, and wastewater intrusion from nearby urban areas add to this complex emission landscape. The mixing of these emissions in the atmosphere often results in secondary pollutants such as $PM_{2.5}$ and ground-level ozone, which have both environmental and public health repercussions (WHO, 2022). Meteorological conditions—including wind patterns, temperature variations, and inversion layers—can exacerbate these effects, as exemplified by historic pollution events like the London Smog of 1952 (Bell & Davis, 2001).

These cumulative, interlinked emission sources make it imperative that rural India be integrated into the national climate action agenda. Rural decarbonisation must be treated not as a peripheral concern but as a core pillar of India's path toward net-zero emissions. This necessitates a multi-pronged approach: regulating pollution-intensive rural industries, promoting low-emission and organic agricultural practices, transitioning from chemical to biofertilizers, establishing decentralized waste management and composting systems, scaling up biogas infrastructure, and expanding real-time rural air monitoring networks. Without such inclusive strategies, India's

progress toward its Nationally Determined Contributions (NDCs) and the Panchamrit commitments announced at COP26 will remain fragmented and socially inequitable. Therefore, rural decarbonisation is not only a climate imperative but also a step toward environmental justice and sustainable rural development.

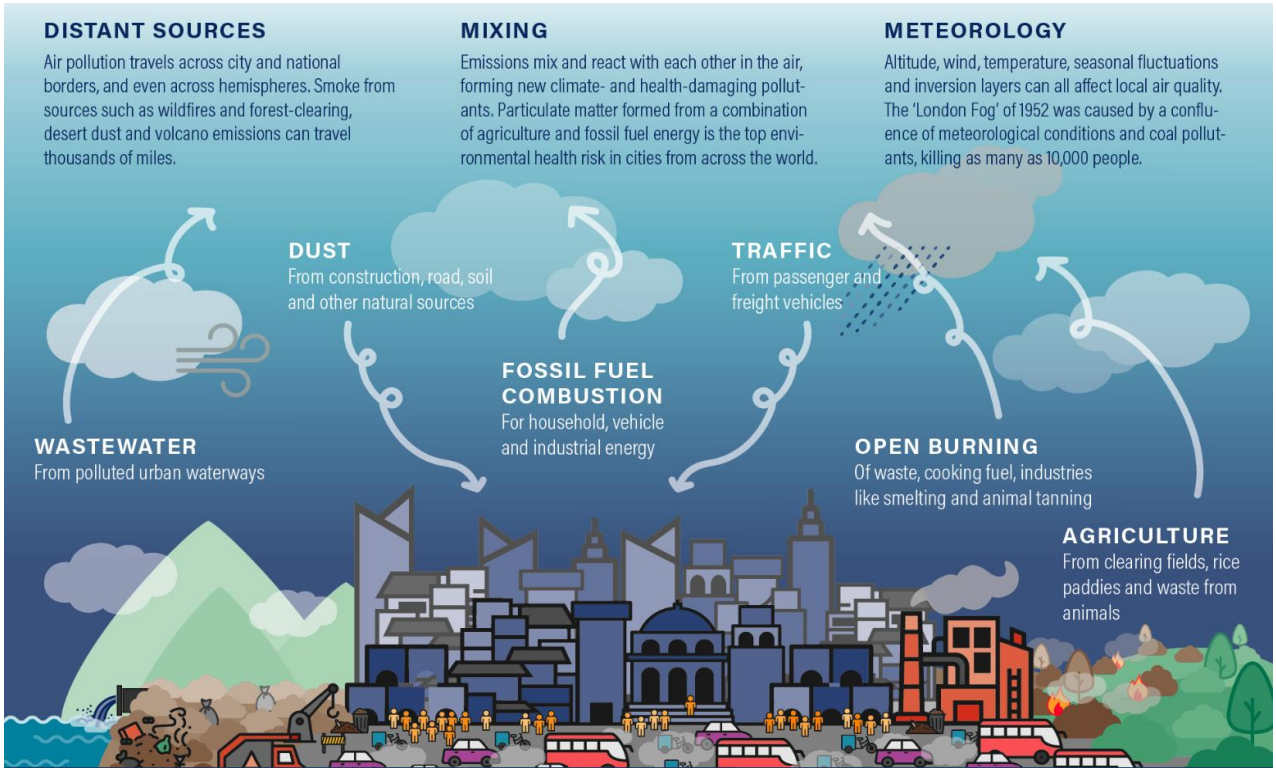

DISTANT SOURCES
Air pollution travels across city and national borders, and even across hemispheres. Smoke from sources such as wildfires and forest-clearing, desert dust and volcano emissions can travel thousands of miles.
MIXING
Emissions mix and react with each other in the air, forming new climate- and health-damaging pollutants. Particulate matter formed from a combination of agriculture and fossil fuel energy is the top environmental health risk in cities from across the world.
METEOROLOGY
Altitude, wind, temperature, seasonal fluctuations and inversion layers can all affect local air quality. The 'London Fog' of 1952 was caused by a confluence of meteorological conditions and coal pollutants, killing as many as 10,000 people.
DUST
From construction, road, soil and other natural sources
TRAFFIC
From passenger and freight vehicles
FOSSIL FUEL COMBUSTION
For household, vehicle and industrial energy
WASTEWATER
From polluted urban waterways
OPEN BURNING
Of waste, cooking fuel, industries like smelting and animal tanning
AGRICULTURE
From clearing fields, rice paddies and waste from animals

Figure 1.5 Sources carbon Emissions in Rural area

1.3 Aim

Aim: To develop a net-zero carbon framework for rural village typologies In Nagpur Metropolitan Region through emission assessment and sustainable interventions.

1.4 Objectives

2 To classify villages by typology (e.g., mixed, agrarian, industrial, peri-urban) for comparative carbon footprint analysis.

3 To quantify Scope 1, 2, and 3 emissions using IPCC Tier 1 methodology across selected rural villages.

4 To propose a scalable framework for Gram Panchayat-level decarbonization in the Nagpur Metropolitan Region.

5 To apply Net Zero Village Planning principles for targeted low-carbon interventions.

1.5 Methodology

Context:

1. Conduct a multi-village comparative analysis by selecting representative case study villages within the Nagpur Metropolitan Region, categorized into mixed-use, agrarian, and industrial typologies.
2. Identify dominant GHG emission sources and carbon-intensive activities in each typology through a combination of literature review, government records (e.g., MSEB, Census), and primary data collection (surveys, field observations).

Theoretical Study:

1. Implement the **IPCC Tier 1 approach** for GHG estimation using emission factors and activity data to compute **Scope 1 (direct), Scope 2 (energy-related), and Scope 3 (indirect) emissions**.
2. Integrate scientific tools and models:
   i. **GHG Inventory tools** (ICAR, TERI rural carbon calculators)
   ii. **Emission intensity metrics** (kg CO_2e/ha, per capita emissions)
   iii. Apply the **UN-Habitat's Net Zero Village Planning framework** (2019) to assess alignment of each typology with net-zero principles (e.g., energy self-sufficiency, closed-loop resource flows).

Analytical Process:

1. **GHG Quantification**:

- Calculate annual emissions by sector (transport, agriculture, energy, waste) across all scopes using the standard formula:
- tCO_2e = Activity Data × Emission Factor × GWP

2. **Comparative Assessment**:

- Conduct cross-typology analysis to identify spatial and functional variations in emission intensity and sustainability performance.
- Develop a typology-emission matrix to visualize carbon hotspots and intervention priorities.

4. **Spatial Analysis**

- Employ GIS mapping and overlay techniques to correlate emissions with land use, infrastructure, and socio-economic layers.

Way Forward:

- Derive typology-specific decarbonisation pathways and recommend an integrated, Panchayat-level implementation framework aligned with India's net-zero targets.
- Identify policy and data gaps, particularly in peri-urban and industrial-influenced rural settings, and suggest institutional mechanisms to support village-level climate action.

1.6 Scope and Limitation

Scope:

1. The scope defines the extent and boundaries of this study on village-level decarbonization planning in the Nagpur Metropolitan Region:
2. Focuses exclusively on rural villages within a metropolitan influence zone, categorized into mixed-use, agrarian, peri-urban, and semi-industrial typologies.
3. Involves quantitative estimation of carbon emissions (Scope 1, 2, 3) using IPCC Tier 1 methodology and tools such as Info Crop and TERI/ICAR carbon calculators.
4. Evaluates low-carbon interventions (e.g., solar energy, LEISA, biogas, circular waste management) through the lens of Net Zero Village Planning principles.
5. Utilizes spatial analysis (GIS) to map emission hotspots and correlate them with land use, infrastructure, and socio-economic factors.
6. Aims to develop a typology-specific, Panchayat-level framework for low-carbon rural transformation applicable to metropolitan rural belts.

Limitations:

1. **Data Gaps**: Incomplete or inconsistent availability of high-resolution, village-level data (e.g., fuel usage, waste quantities, commuting patterns) may limit the precision of emission estimates.
2. **Limited Geographic Scope**: The study is confined to select villages within the Nagpur Metropolitan Region and may not be fully representative of rural contexts across other Indian states or eco-regions.
3. **Typology-Based Variation**: Differences in governance capacity, infrastructure availability, and policy implementation across village typologies could affect the generalizability of proposed decarbonization pathways.
4. **Tool and Model Constraints**: Reliance on Tier 1 emission factors and secondary modeling tools may not capture all micro-level emissions nuances. Advanced field instruments or Tier 2/3 methodologies were beyond scope.

Chapter -2
LITERATURE STUDY

2.1 IPCC Methodologies (Tier 1, 2, 3)

The Intergovernmental Panel on Climate Change (IPCC) provides an internationally recognized framework for estimating greenhouse gas (GHG) emissions through its Guidelines for National Greenhouse Gas Inventories (2006), which were further refined in 2019. These guidelines are crucial for ensuring transparency, consistency, and comparability in national and sub-national emissions reporting. Their tiered structure allows for flexibility based on the availability of data, technical expertise, and institutional capacity (AR6 Synthesis Report: Climate Change 2023. IPCC, 2023).

In the context of urban planning, these methodologies support cities in developing accurate and scalable GHG inventories. Urban environments are complex systems where emissions arise from diverse sources such as transportation, buildings, energy systems, waste management, and land-use change. The IPCC guidelines enable local governments to choose appropriate methods that reflect their data capabilities while maintaining methodological alignment with national reporting.

Tiered Approach

The IPCC's tiered approach is divided into three levels, each offering increasing detail and accuracy:

Table 2.1: IPCC Tiered Methodology for Emissions Estimation

Tier	Description	Data Requirement	Examples in Rural Context
Tier 1	Uses IPCC default emission factors and simple data	Basic activity data (e.g., litres of diesel, kg of fertilizer)	Estimating emissions from diesel pumps, livestock CH_4 using global averages
Tier 2	Uses country-specific emission factors and disaggregated data	National EFs, crop-specific/livestock-specific parameters	CH_4 emissions using Indian cattle breed factors, regional cropping patterns
Tier 3	Uses advanced models, direct measurements, geospatial tools	Dynamic models, sensors, satellite data	NDVI-based carbon loss tracking, climate-resilient crop modeling

Tier 1: Basic Estimation Method

Tier 1 is the entry-level approach and is designed for areas with limited data access or technical capacity. It uses global default emission factors provided by the IPCC and requires simple activity data—such as total fuel consumption, number of vehicles, kilograms of fertilizer used, or livestock

population. While Tier 1 methods may result in broader uncertainty ranges, they are particularly useful for preliminary assessments or for regions without established emissions monitoring systems. In urban areas just beginning their climate planning efforts, Tier 1 can serve as a foundational step toward more detailed assessments. (Refer fig No. 2.1 and Table 2.1)

Tier 2: Intermediate Method with National Specificity

This tier introduces greater specificity by incorporating country-specific emission factors and more disaggregated activity data. It considers regional variations, such as different vehicle types and efficiencies, energy mixes, or agricultural practices. For instance, in urban areas, Tier 2 might involve distinguishing between energy use in residential, commercial, and industrial buildings, or assessing transportation emissions by vehicle type and fuel efficiency. The increased accuracy of Tier 2 makes it suitable for cities developing targeted mitigation strategies or seeking to align with national GHG inventory reporting. (Refer fig No. 2.1 and Table 2.1)

Tier 3: Advanced Modeling and Measurement Techniques

Tier 3 involves sophisticated tools such as dynamic simulation models, high-resolution satellite or GIS-based data, continuous emission monitoring systems (CEMS), and direct field measurements. These techniques are often employed in national-level inventories or scientific research but are increasingly being adopted by data-rich metropolitan areas with robust monitoring infrastructure Tier 3 supports high-precision urban climate planning, enabling cities to evaluate the impact of specific policies and technologies in real time. (Refer fig No. 2.1 and Table 2.1)

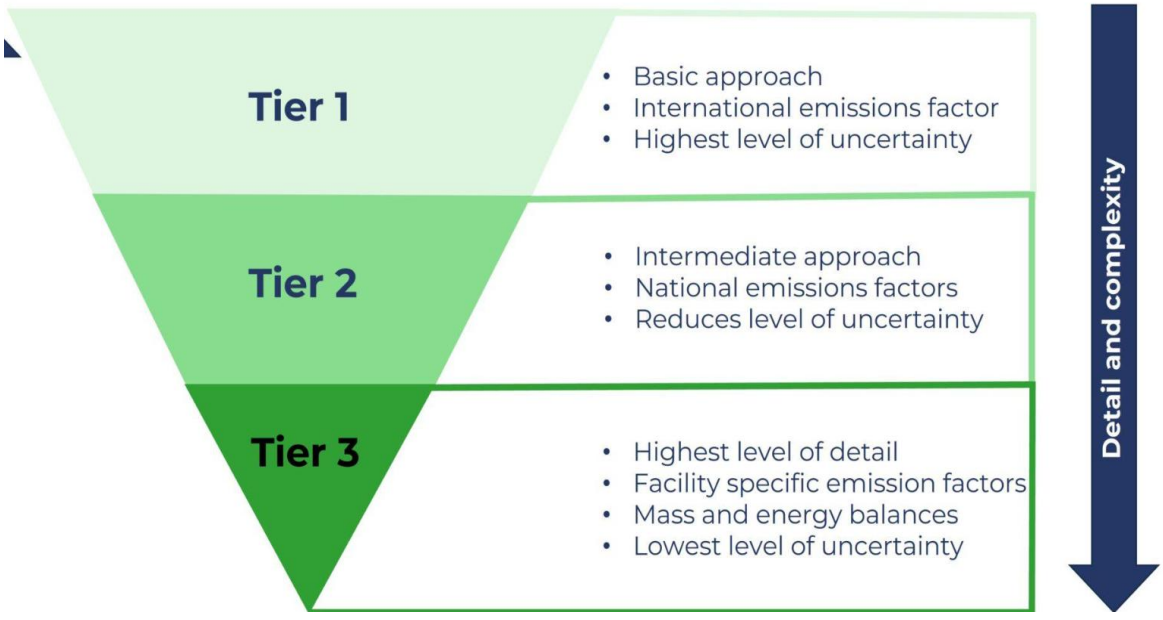
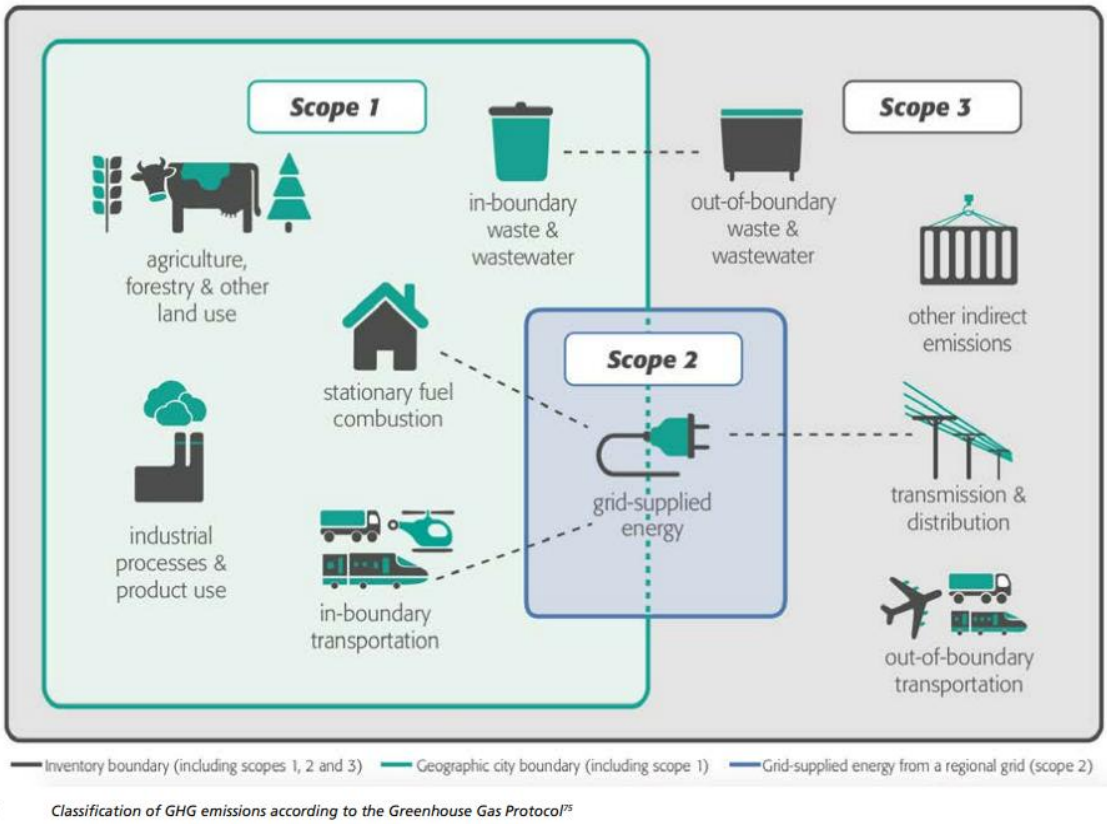


Figure 2.1 IPCC Tiers of Emission Estimation: Levels of Methodological Complexity

Challenges and Opportunities

Despite the utility of IPCC methods, urban areas often face challenges such as data gaps, fragmented jurisdictional responsibilities, and limited technical capacity. Addressing these requires investment in data infrastructure, capacity building, and partnerships between city governments, research institutions, and national agencies. However, the growing availability of digital tools—such as open-source GHG inventory platforms, urban data dashboards, and AI-enhanced remote sensing—offers new opportunities to apply higher-tier methodologies even in resource-constrained cities.

2.2 GHG Protocol : Scope 1, 2, 3 classification



.3 *Classification of GHG emissions according to the Greenhouse Gas Protocol*[75]

Figure 2.2 Classification of GHG emissions according to the green house gas protocol

To systematically classify greenhouse gas (GHG) emissions based on their origin and the level of control that can be exerted over them, this study utilizes the Scope 1–2–3 emissions framework as established by the Greenhouse Gas Protocol. This internationally recognized methodology offers a structured approach to assessing emissions by grouping them according to their physical and operational proximity to the area of study, which is particularly useful for localized urban or rural climate planning (World Resources Institute (WRI) & World Business Council for Sustainable Development (WBCSD), 2004).

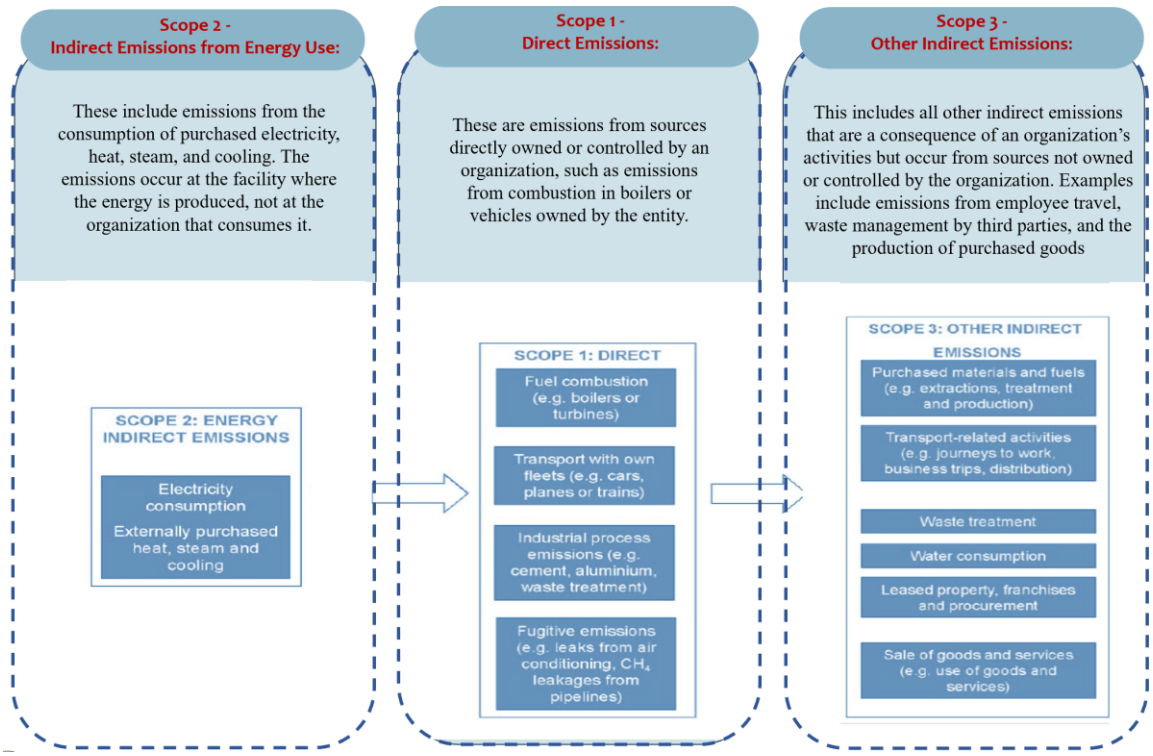

Scope 2 -
Indirect Emissions from Energy Use:
These include emissions from the consumption of purchased electricity, heat, steam, and cooling. The emissions occur at the facility where the energy is produced, not at the organization that consumes it.
SCOPE 2: ENERGY INDIRECT EMISSIONS
Electricity consumption
Externally purchased heat, steam and cooling
Scope 1 -
Direct Emissions:
These are emissions from sources directly owned or controlled by an organization, such as emissions from combustion in boilers or vehicles owned by the entity.
SCOPE 1: DIRECT
Fuel combustion (e.g. boilers or turbines)
Transport with own fleets (e.g. cars, planes or trains)
Industrial process emissions (e.g. cement, aluminium, waste treatment)
Fugitive emissions (e.g. leaks from air conditioning, CH_4 leakages from pipelines)
Scope 3 -
Other Indirect Emissions:
This includes all other indirect emissions that are a consequence of an organization's activities but occur from sources not owned or controlled by the organization. Examples include emissions from employee travel, waste management by third parties, and the production of purchased goods
SCOPE 3: OTHER INDIRECT EMISSIONS
Purchased materials and fuels (e.g. extractions, treatment and production)
Transport-related activities (e.g. journeys to work, business trips, distribution)
Waste treatment
Water consumption
Leased property, franchises and procurement
Sale of goods and services (e.g. use of goods and services)

Figure 2.3 Scope-wise Classification of Emissions in Rural Villages

Scope 1 covers all direct emissions originating from within the defined geographical boundary. In a village or small urban settlement, these would include GHG emissions resulting from the on-site use of diesel in irrigation equipment, cooking with firewood, methane emissions from livestock, and nitrous oxide emissions due to fertilizer application. These emissions fall entirely under local jurisdiction and are often the most immediately actionable. (Refer fig No. 2.3)

Scope 2 includes indirect emissions from the generation of purchased electricity consumed within the area. Although the electricity is typically produced off-site—such as from fossil-fuel-powered plants—it is used locally for essential services like residential lighting, school operations, or water supply through electric pumps. These emissions are less directly controllable but can be influenced through energy efficiency or clean energy initiatives at the community level. (Refer fig No. 2.3)

Scope 3 encompasses other indirect emissions that occur outside the local boundary but are a result of activities within it. These might include emissions from the transportation of agricultural produce to regional markets, the carbon footprint of construction materials transported from other areas, and upstream emissions from the production of goods like liquefied petroleum gas (LPG) or chemical fertilizers. While more complex to measure and mitigate, Scope 3 emissions highlight the importance of broader supply chain and policy-level interventions. (Refer fig No. 2.3)

By adopting the GHG Protocol's tiered classification, urban and regional planners can better understand where localized interventions (Scope 1 and 2) can be most effective, and where wider, system-level changes (Scope 3) need to be considered in collaboration with regional or national stakeholders.

Table 1.2 : Scope-wise Classification of Emissions in Rural Villages

Scope	Definition	Examples in Rural Context	Emission Type
Scope 1	Direct emissions from within the village	Diesel in pumps, livestock CH_4, N_2O from fertilizer, firewood combustion	CO_2, CH_4, N_2O
Scope 2	Indirect emissions from purchased electricity	Household and public electricity use from the grid (e.g.,irrigation, streetlights)	CO_2 (from power plants)
Scope 3	Other indirect emissions from upstream /downstream sources	Transport to market, LPG/urea production, cement and steel in housing (PMAY-G, roads, etc.)	CO_2, CH_4 (lifecycle-based)

2.3 UN-Habitat's Net Zero Village Planning Principles

Figure 2.4 Ten Principles for Revitalizing Rural Areas and Creating Zero Carbon Villages

UN-Habitat has outlined a set of integrated planning principles to guide the development of sustainable, climate-resilient villages that align with global climate targets. These principles support the overarching goal of achieving net-zero greenhouse gas (GHG) emissions, in line with the ambition to limit global temperature rise to 1.5°C by the year 2050 .
(Refer fig No. 2.4)

Conceptual Pillars for Sustainable Village Design

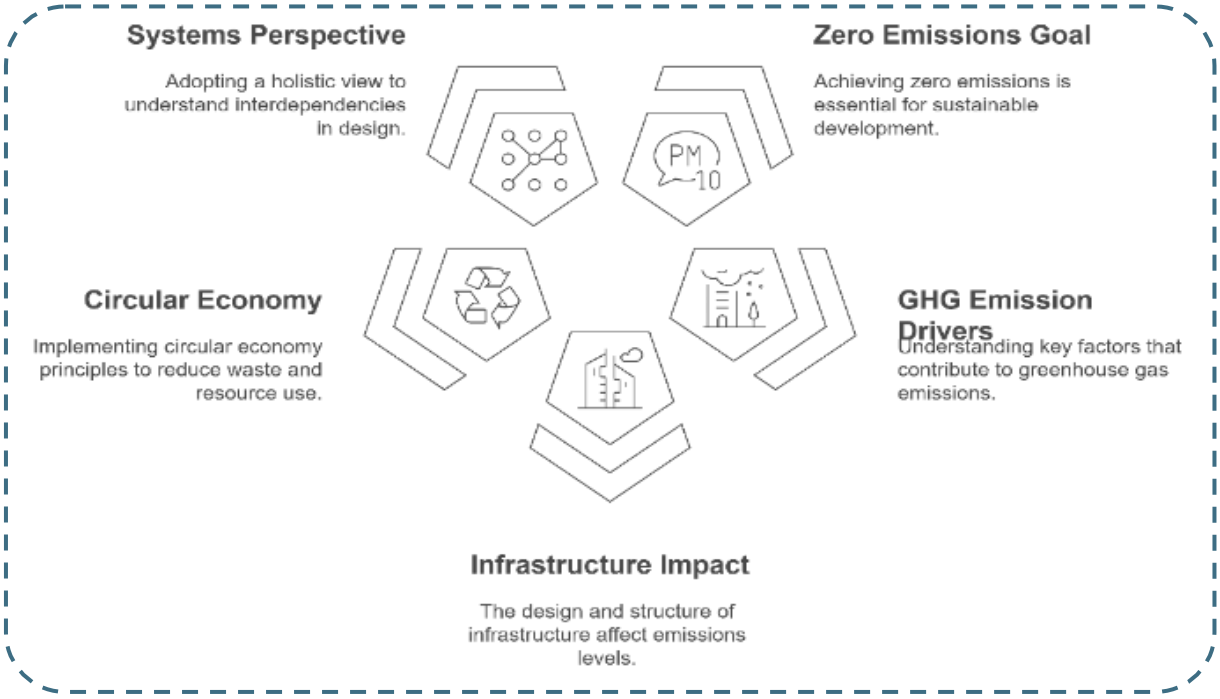

Systems Perspective
Adopting a holistic view to understand interdependencies in design.
Zero Emissions Goal
Achieving zero emissions is essential for sustainable development.
PM 10
Circular Economy
Implementing circular economy principles to reduce waste and resource use.
GHG Emission Drivers
Understanding key factors that contribute to greenhouse gas emissions.
Infrastructure Impact
The design and structure of infrastructure affect emissions levels.

Figure 2.5 Sustainable village design: conceptual pillar

1. Net-Zero Emissions Goal:

The central aim of sustainable village planning under UN-Habitat's framework is to eliminate net GHG emissions. This involves reducing emissions across all sectors of village life—energy, transport, agriculture, waste, and buildings—while promoting carbon sinks and offset mechanisms where necessary. The design approach emphasizes long-term environmental and climate responsibility.

2. Key Drivers of GHG Emissions

Urban form and infrastructure significantly influence emissions outcomes. Elements such as settlement density, spatial layout, land use patterns, and the management of energy, water, and waste systems determine a village's carbon footprint. Compact, mixed-use developments with efficient infrastructure reduce travel distances, support renewable energy integration, and minimize energy losses.

3. Role of Built Environment and Infrastructure

Strategic planning of buildings and infrastructure is critical in minimizing both direct emissions (e.g., from fossil fuel use in homes and transport) and indirect emissions (e.g., emissions embedded in construction materials or electricity use). Emphasizing energy-efficient design, passive cooling, and climate-responsive architecture helps reduce operational emissions.

4. Circular Economy Integration

Sustainable village design incorporates circular economy principles, aiming to minimize waste and maximize resource efficiency. This includes promoting the reuse and recycling of materials, sustainable consumption patterns, and regenerative practices in food and materials systems. Reducing the demand for virgin resources inherently reduces upstream GHG emissions.

5. Holistic Systems Approach

A systems-thinking perspective is central to net-zero planning. The interdependencies among energy, water, food systems, and waste management must be acknowledged and optimized in an integrated way. This ensures resilience, efficiency, and sustainability by avoiding siloed interventions that could lead to unintended environmental consequences. (Refer fig No. 2.5)

2.4 Methodology for Estimating Greenhouse Gas Emissions: Activity Data and Emission Factors

To measure emissions accurately, planners compile GHG inventories using data from national databases, local surveys, and regional emission tracking systems. Calculations rely on either country-specific emission factors, where available, or default factors provided by the IPCC when localized data is lacking (IPCC, 2014).

The general formula for estimating emissions is:

$$\text{Emissions}_{\text{Gas}} = \sum(\text{A} \times \text{EF})$$

Emissions (Gas) = A × EF

Where:

A is the activity data, such as the amount of fuel used, kilometers traveled, or volume of waste generated.

EF is the emission factor, representing the average emissions associated with one unit of activity (e.g., tons of CO_2 per MWh of electricity).

This approach allows for flexible but standardized emissions accounting, which is essential for tracking progress toward net-zero goals.

Chapter -3
DELINEATION OF STUDY AREA

3.1 Typology of Rural Villages for Targeted Planning Interventions

In order to implement need-based and context-sensitive development strategies, rural areas can be categorized into distinct typologies based on land use, economic functions, ecological sensitivity, and socio-cultural characteristics. The classification of villages into six broad categories—Agricultural Villages, Peri-Urban Villages, Tourism Villages, Eco-Sensitive Villages, Special Function Villages, and Remote/Tribal Villages—provides a framework for tailored planning and policy interventions.

Agricultural Villages, which are either rainfed or irrigated, are primarily dependent on farming and thus require interventions focused on watershed development, drought-resilient cropping systems, and sustainable irrigation infrastructure.

Peri-Urban Villages, including urbanizing and urban fringe villages, are experiencing rapid land use changes and urban sprawl, necessitating integrated planning for infrastructure expansion, mixed land use regulation, and pollution management.

Tourism Villages include eco-tourism and cultural tourism subtypes that emphasize biodiversity conservation and the promotion of heritage, respectively. These villages can benefit from initiatives aimed at sustainable tourism infrastructure, eco-friendly accommodations, and local craft development.

Eco-Sensitive Villages comprise forest-based and water-sensitive settlements, which demand specialized environmental measures such as afforestation, forest conservation, wetland management, and pollution control.

Special Function Villages include industrial and mining villages, often hosting pollution-intensive activities. These areas require stringent industrial zoning, emission mitigation technologies, and welfare schemes for affected communities.

Lastly, **Remote/Tribal Villages** include tribal communities with unique socio-cultural traditions and geographically isolated villages with poor connectivity. These regions need focused efforts in preserving indigenous knowledge systems, while also improving access to healthcare, education, roads, electricity, and digital infrastructure.

Recognizing and classifying rural villages through this typology ensures that interventions—whether in terms of infrastructure, livelihood enhancement, or climate resilience—are context-appropriate and equitable.

Table 2.1 Categorisation of villages

Category	Subcategory	Description	Key Features
1. Agricultural Villages	***Rainfed Agricultural Villages***	Villages dependent on monsoon rains for agriculture.	Focus on watershed development, drought-resistant crops, and soil conservation techniques.
	Irrigated Agricultural Villages	Villages with access to irrigation facilities for farming.	Emphasis on canal-based irrigation, micro-irrigation systems, and sustainable water management.
2. Peri-Urban Villages	***Urbanizing Villages***	Villages transitioning towards urban characteristics due to proximity to urban areas.	Land use changes, increasing demand for urban infrastructure, and mixed economic activities.
	Urban Fringe Villages	Villages on the immediate boundary of cities.	Pressure for land conversion, urban sprawl, and demand for housing and commercial development.
3. Tourism Villages	***Eco-Tourism Villages***	Villages promoting sustainable tourism based on natural ecosystems.	Focus on preserving biodiversity, eco-friendly accommodations, and visitor awareness programs.
	Cultural Tourism Villages	Villages showcasing unique cultural or historical heritage.	Development of heritage sites, cultural festivals, and local handicrafts markets.
4. Eco-Sensitive Villages	***Forest-Based Villages***	Villages located in or near forest ecosystems.	Dependency on forest produce, emphasis on afforestation, and forest conservation measures.
	Water-Sensitive Villages	Villages near significant water bodies or wetlands.	Focus on wetland management, water conservation, and prevention of water pollution.
5. Special Function Villages	***Industrial Villages***	Villages hosting small-scale or large-scale industrial units.	Industrial zoning, pollution control measures, and infrastructure for industrial activities.
	Mining Villages	Villages involved in mining activities.	Regulation of mining practices, environmental safeguards, and community welfare programs.
6. Tribal Villages	***Tribal Villages***	Villages with significant tribal populations and unique socio-cultural practices.	Promotion of tribal heritage, access to healthcare and education, and preservation of traditional livelihoods.

3.2 Comparative Rating of Rural Village Typologies Based on Carbon Emission Potential

Understanding carbon emission patterns across different rural village typologies is essential for tailoring decarbonisation strategies at the grassroots level. A classification of rural villages based on their land use, economic activities, and ecological context reveals substantial variation in their contribution to greenhouse gas (GHG) emissions.

Agricultural Villages, particularly Rainfed Agricultural Villages, contribute moderately to high levels of emissions due to open burning of crop residues, methane emissions from livestock, and nitrous oxide released from excessive fertilizer application. Irrigated Agricultural Villages show even higher emissions, primarily driven by methane from flooded paddy fields and the diesel-powered pumps used for irrigation (Census India, 2011; City Population, 2022).

Peri-Urban Villages rank among the highest contributors to rural emissions. Urbanizing Villages experience elevated emissions from transportation, construction, and energy use driven by rapid land use change and urban sprawl. Urban Fringe Villages show very high emission profiles due to the presence of energy-intensive infrastructure, traffic congestion, and proximity to industrial zones (Census India, 2011).

Tourism Villages vary considerably in their emission intensity. Eco-Tourism Villages are characterized by low emissions, supported by sustainable practices and limited energy demand. In contrast, Cultural Tourism Villages experience moderate emissions, mainly from transportation and seasonal tourist flows (Census India, 2011; Sustainable Tourism Reports).

Eco-Sensitive Villages—including Forest-Based and Water-Sensitive Villages—demonstrate very low to low emissions. The presence of natural carbon sinks such as forests and wetlands significantly offsets localized emissions, especially where afforestation and conservation practices are effectively enforced (Census India, 2011; City Population, 2022).

Special Function Villages, particularly Industrial and Mining Villages, exhibit the highest emissions across all rural typologies. Emissions from these villages are attributed to coal usage, thermal power generation, methane release from mining activities, and energy-intensive transport (Census India, 2011; CPCB, 2021).

Finally, Remote/Tribal Villages, including Tribal and Remote Isolated Villages, contribute the least to carbon emissions. These villages are often carbon-neutral or even carbon-negative due to their dependence on subsistence-based livelihoods, minimal transportation, and limited energy access (Census India, 2011; City Population, 2022).

The emission intensity ratings—ranging from very low (★☆☆☆☆) in eco-sensitive a nd tribal settings to very high (★★★★★) in industrial and urbanizing villages—underscore the importance of adopting typology-specific interventions. While low-emission villages require support to preserve their ecological resilience, high-emission zones demand targeted policies for energy transition, pollution control, and green infrastructure developmen

Category	Subcategory	Primary Carbon Emission Sources	Estimated Contribution to Emissions	Rating (1-5)	Notes/References
Agricultural Villages	***Rainfed Agricultural Villages***	Open burning of crop residues, methane from livestock, nitrous oxide from fertilizers, and energy use for irrigation.	**Moderate to High**	★★★★☆	Open burning and fertilizer use increase the carbon footprint significantlyCensus 2011 India www.censusindia.co.in City Population .
	Irrigated Agricultural Villages	Methane emissions from paddy fields, high fertilizer use, and diesel-powered pumps for irrigation.	**High**	★★★★☆	Fertilizer and irrigation practices contribute heavily to emissions www.censusindia.co.in City Population .
Peri-Urban Villages	***Urbanizing Villages***	High emissions from construction, transportation, and increasing energy demand due to urban sprawl.	**High**	★★★★☆	Urbanization drives energy-intensive activitiesCensus 2011 India Census India 2011 .
	Urban Fringe Villages	Emissions from IT hubs, vehicular traffic, and energy-intensive infrastructure development.	**Very High**	★★★★★	Dominant contributors due to rapid infrastructure growthCensus India 2011 City Population .
Tourism Villages	***Eco-Tourism Villages***	Low emissions, primarily from visitor transportation; eco-tourism practices limit environmental impact.	**Low**	★☆☆☆☆	Sustainable tourism practices minimize carbon outputCensus 2011 India www.censusindia.co.in .

Category	*Subcategory*	Primary Carbon Emission Sources	Estimated Contribution to Emissions	Rating (1-5)	Notes/References
Eco-Sensitive Villages	***Forest-Based Villages***	Minimal emissions; high carbon sink potential due to forest cover.	**Very Low**	★☆☆☆☆	Emissions offset by extensive tree cover and natural processes www.censusindia.co.in City Population
	Water-Sensitive Villages	Limited emissions, mainly from small-scale aquaculture and local transportation.	**Low**	★☆☆☆☆	Effective natural ecosystem management reduces footprintCensus India 2011 City Population.
Special Function Villages	***Industrial Villages***	High emissions from thermal power plants, coal usage, and other industrial processes.	**Very High**	★★★★★	Energy-intensive industries are dominant contributors www.censusindia.co.in City Population
	Mining Villages	High emissions from coal mining, methane release, and associated transport.	**Very High**	★★★★★	Methane from mining and associated processes are significant Census 2011 India Census India 2011
Remote/Tribal Villages	***Tribal Villages***	Minimal emissions; largely subsistence-based activities with low energy usage.	**Very Low**	★☆☆☆☆	Carbon-neutral or carbon-negative due to forest dependency www.censusindia.co.in City Population
	Remote Isolated Villages	Negligible emissions; transportation is a minor contributor, but overall activities are low-impact.	**Very Low**	★☆☆☆☆	Geographic isolation and low activity limit emissions Census India 2011 City Population

Table 3.2 Rating Of Villages As Per Highest Emission

3.3 Cluster Selection and Characteristics :

The classification of villages into typologies such as agricultural, mixed, and industrial is conducted based on seven character zones as defined under the Rural–Urban Transect, described in Section 11.4 of the Development Plan.

These seven character zones are identified using a combination of factors including:

- Land suitability analysis
- Economic base
- Infrastructure provision
- Natural land conservation
- Jobs-to-housing balance

The seven character zones used in classification are as follows:

- Highly Urban
- Urban
- Suburban
- Rural–Suburban
- Prime Agriculture
- Conservation
- Forest/Hills

The following parameters are employed to determine and classify village typologies in the Development Plan:

Table 3.3 Factors Used for Village Typology Classification:

Parameter	Use in Classification
Land Use & Suitability	Based on percentage of agricultural land, presence of industrial zones, and scope for mixed-use development.
Economic Base	Classified into primary (agriculture), secondary (manufacturing/industrial), or tertiary (services) activities.
Infrastructure Provision	Evaluated through the availability of roads, public transport, utilities, and water supply infrastructure.
Development Density	Measured in dwelling units per hectare; typically higher in urban and mixed-use areas, lower in rural areas.
Transport Connectivity	Proximity to national/state highways (NH/SH), MIDC areas, or railway lines—important for industrial/mixed-use classification.
Existing Land Use Analysis (ELU)	Refers to the percentage of land currently under agricultural, residential, or industrial use.
Grain of Development	Assesses the spatial distribution of settlements—whether dispersed, linear (along corridors), or clustered in nodes.

3.4 Selection of Village Typologies for Decarbonisation Planning

Table 3.4 Cluster Selection and characteristics

Village Cluster	Typology	Justification Based on Plan Standards
Tarsa–Nawegaon–Ashti (Mauda Tehsil)	Agricultural	>81% ELU as agriculture, NTPC influence is passive, low industrialization
Kadoli–Asoli–Mahalgaon (Kamptee Tehsil)	Mixed	Balanced residential (8.82%), industrial (10.32%), and agriculture (62.9%) use – moderate transition zone
Kirmiti Cluster (Hingna Tehsil)	Industrial	Major MIDC presence, high emissions, industries in steel, chemical, plastic – core secondary sector base

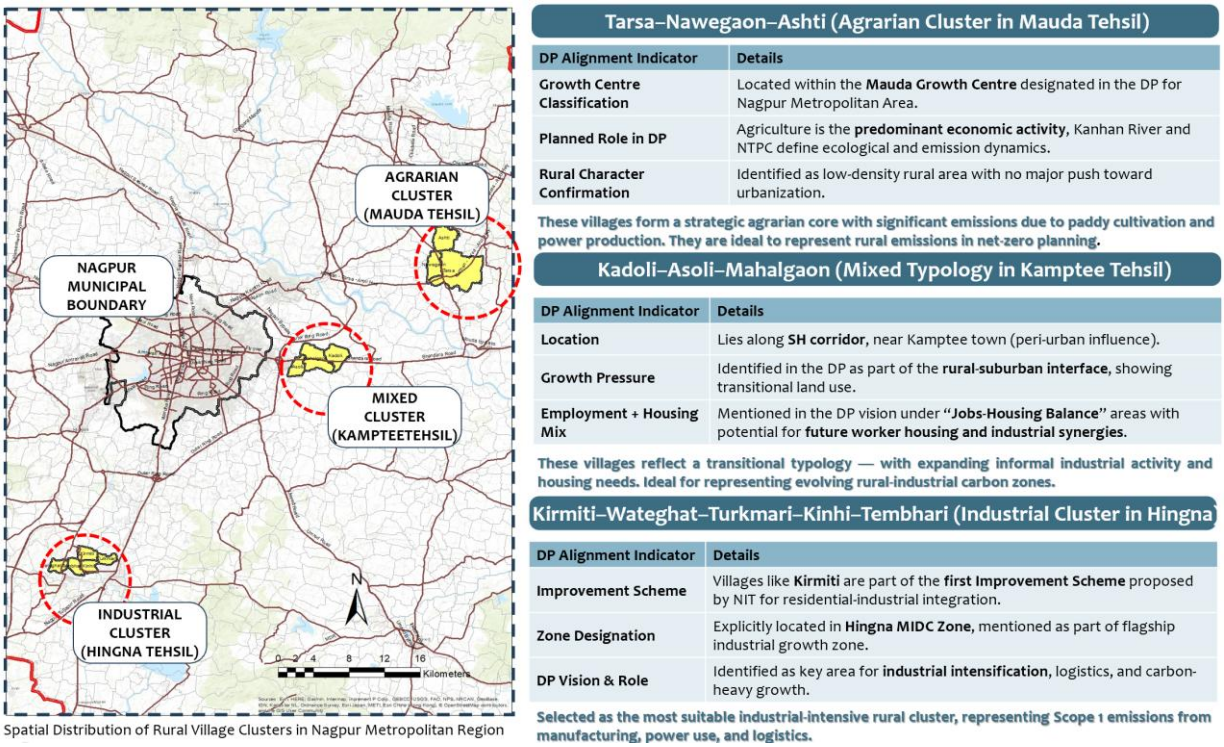

AGRARIAN CLUSTER (MAUDA TEHSIL)
NAGPUR MUNICIPAL BOUNDARY
MIXED CLUSTER (KAMPTEETEHSIL)
INDUSTRIAL CLUSTER (HINGNA TEHSIL)
N
0 2 4 8 12 16
Kilometers
Spatial Distribution of Rural Village Clusters in Nagpur Metropolitan Region
Tarsa–Nawegaon–Ashti (Agrarian Cluster in Mauda Tehsil)
DP Alignment Indicator | Details
Growth Centre Classification | Located within the Mauda Growth Centre designated in the DP for Nagpur Metropolitan Area.
Planned Role in DP | Agriculture is the predominant economic activity, Kanhan River and NTPC define ecological and emission dynamics.
Rural Character Confirmation | Identified as low-density rural area with no major push toward urbanization.
These villages form a strategic agrarian core with significant emissions due to paddy cultivation and power production. They are ideal to represent rural emissions in net-zero planning.
Kadoli–Asoli–Mahalgaon (Mixed Typology in Kamptee Tehsil)
DP Alignment Indicator | Details
Location | Lies along SH corridor, near Kamptee town (peri-urban influence).
Growth Pressure | Identified in the DP as part of the rural-suburban interface, showing transitional land use.
Employment + Housing Mix | Mentioned in the DP vision under "Jobs-Housing Balance" areas with potential for future worker housing and industrial synergies.
These villages reflect a transitional typology — with expanding informal industrial activity and housing needs. Ideal for representing evolving rural-industrial carbon zones.
Kirmiti–Wateghat–Turkmari–Kinhi–Tembhari (Industrial Cluster in Hingna)
DP Alignment Indicator | Details
Improvement Scheme | Villages like Kirmiti are part of the first Improvement Scheme proposed by NIT for residential-industrial integration.
Zone Designation | Explicitly located in Hingna MIDC Zone, mentioned as part of flagship industrial growth zone.
DP Vision & Role | Identified as key area for industrial intensification, logistics, and carbon-heavy growth.
Selected as the most suitable industrial-intensive rural cluster, representing Scope 1 emissions from manufacturing, power use, and logistics.

Figure 3.1 Spatial Distribution Map of Rural Village Clusters in Nagpur Metropolitan Region

3.4.1 Mixed Cluster: Kadoli – Asoli- Mahalgaon

The villages of Kadoli, Asoli, and Mahalgaon form a mixed rural-urban cluster situated within the Kamptee Tehsil of Nagpur District. This cluster falls under the jurisdiction of the Nagpur Metropolitan Area (NMA) and is governed by the Nagpur Improvement Trust (NIT), highlighting its administrative integration into broader metropolitan planning frameworks (Town and Country

Planning Organization (TCPO), 2021).

These villages collectively represent a transitional zone on the rural-urban continuum. Their development is shaped by both agricultural livelihoods and increasing urban influence due to their proximity to Kamptee town, a growing urban center. This dual identity makes the cluster a key candidate for integrated planning approaches that balance economic diversification with sustainable resource management.

Asoli

Asoli's population is expected to grow from 1,185 in 2001 to 1,363 by 2032, reflecting gradual urban influence. Located near Kamptee, Asoli is undergoing peri-urban transformation, marked by infrastructural growth and mixed land-use trends. The village has been identified in the development plan for strategic land allocations, including sites for a district jail, exhibition grounds, and public utilities. This suggests its emerging role as a service node within the metropolitan periphery.

Mahalgaon

Mahalgaon, with a projected population increase from 643 in 2011 to 739 by 2032, remains rooted in agriculture but is also influenced by its location near the urban fringe. The village is characterized by black cotton soil, which supports a diverse cropping system dominated by soybean, cotton, paddy, tur (pigeon pea), and wheat. The prevalence of double-cropping—with strong Kharif and Rabi agricultural cycles—demonstrates the area's high agricultural productivity. Notably, soybean cultivation is prominent across the district, occupying approximately 1.93 lakh hectares, emphasizing the crop’s regional significance.

Kadoli

While specific demographic data for Kadoli is not detailed, its inclusion in this cluster indicates shared characteristics with Asoli and Mahalgaon, particularly in terms of location, soil profile, and development trajectory. Kadoli contributes to the cluster's spatial continuity and socio-economic interlinkages, making it an integral part of planning strategies that address peri-urban growth, infrastructure needs, and agricultural transitions.

Together, the Kadoli–Asoli–Mahalgaon cluster exemplifies the emerging mixed typology of settlements at the urban edge—where agriculture, infrastructure, and urban services coexist. This spatial form requires context-sensitive policies that address both urban expansion pressures and the need to sustain traditional livelihoods.

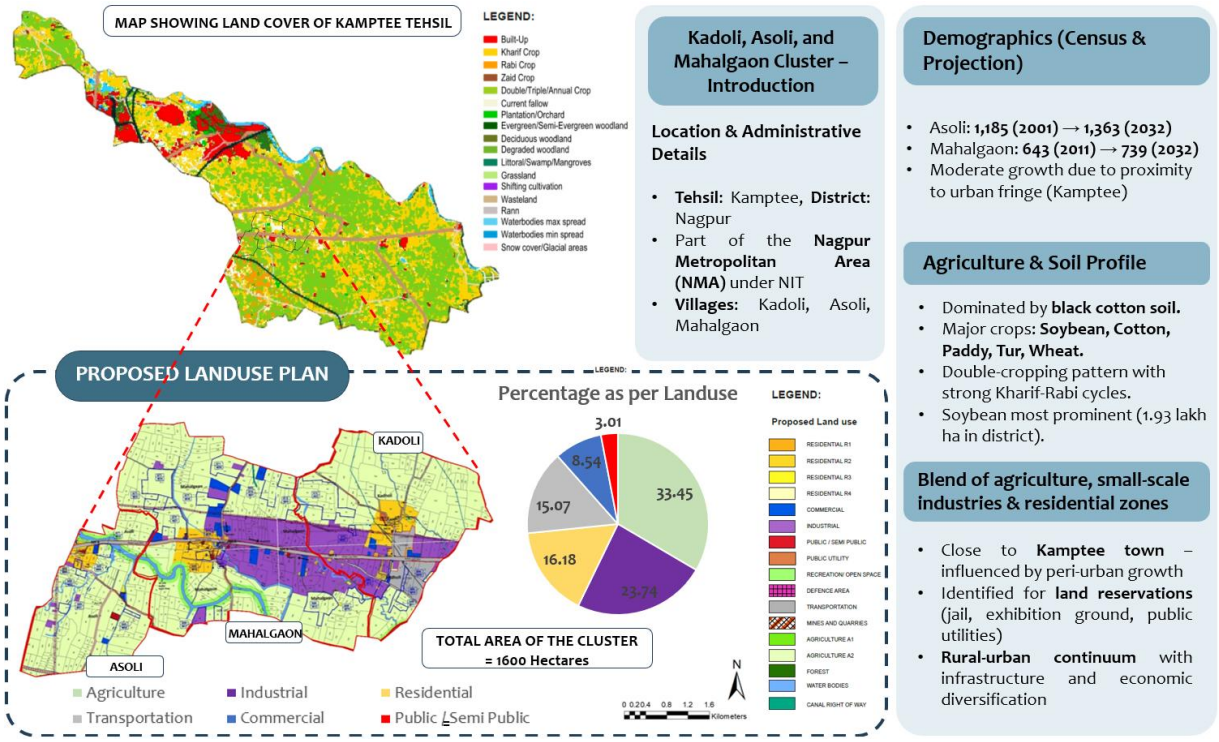


Figure 3.2 Spatial and Functional Profile of the Mixed Village Cluster (Kadoli-Asoli-Mahalgaon)

This figure illustrates the existing land cover of Kamptee Tehsil and the proposed land use distribution for the Kadoli–Asoli–Mahalgaon cluster, covering an area of 1600 hectares. The cluster exhibits a blend of agricultural zones, small-scale industries, and expanding residential areas influenced by its peri-urban proximity to Kamptee town. The land use plan reflects functional zoning aimed at balancing agricultural productivity, urban expansion, and infrastructure development within the Nagpur Metropolitan Area.

3.4.2 Industrial Cluster: Kimiti-Wateghat-Tembhari- Turkmari- Kinhi

Located in the Hingna Tehsil of Nagpur District, the cluster comprising Kirmiti, Wateghat, Tembhari, Turkmari, and Kinhi has evolved into a rural industrial hub. This transformation has been driven by the expansion of the Hingna Maharashtra Industrial Development Corporation (MIDC) zone, which has significantly reshaped land use and economic activity in the area (Town and Country Planning Organization (TCPO), 2021).

The region was originally characterized by black cotton soil, known for its high fertility and suitability for agriculture. However, over the years, much of this agricultural land has been converted for industrial purposes, limiting traditional farming practices and intensifying land-use change.

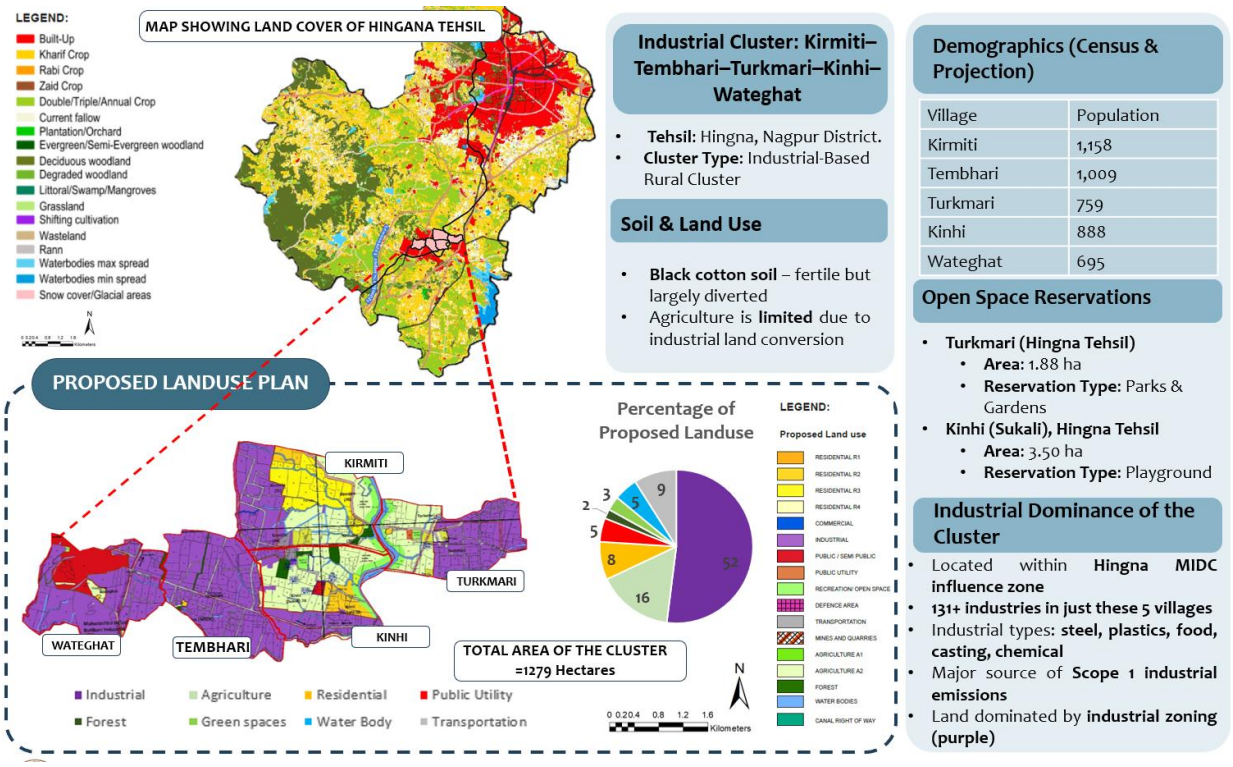


Figure 3.3 Spatial and Functional Profile of Industrial Village Cluster(Kirmiti-Tembhari-Wateghat-Turkmari-Kinhi)

The cluster has over 131 industrial units, covering sectors such as steel, plastic manufacturing, food processing, metal casting, and chemicals. This concentration of industrial activity designates the area as a high-emission zone, particularly with respect to Scope 1 GHG emissions—those directly emitted from production and energy use on-site (World Resources Institute (WRI) & World Business Council for Sustainable Development (WBCSD), 2004).

Specific land reservations within the cluster reflect attempts to balance industrial development with basic amenities and green infrastructure:

- Turkmari, with an area of 1.88 hectares, has land allocated for parks and gardens, enhancing local livability.
- Kinhi (Sukali) features a 3.50-hectare plot designated for a playground, indicating a recognition of community recreational needs even within a heavily industrialized context.

The dominant zoning pattern is industrial, marked by extensive 'purple' land use classification, typical of regions under MIDC influence. This zoning prioritizes industrial expansion and related infrastructure, impacting surrounding land values, settlement patterns, and ecological systems.

The rapid industrialization of this cluster necessitates targeted environmental and urban management strategies. Planners must address the dual challenges of controlling emissions and ensuring inclusive development—with provisions for housing, green space, and essential services for workers and local residents. The area's strategic importance within the district's economic framework highlights the need for sustainable industrial planning that aligns with regional development goals and environmental standards.

3.4.3 Agrarian Cluster: Tarsa- Nawegaon- Asthi

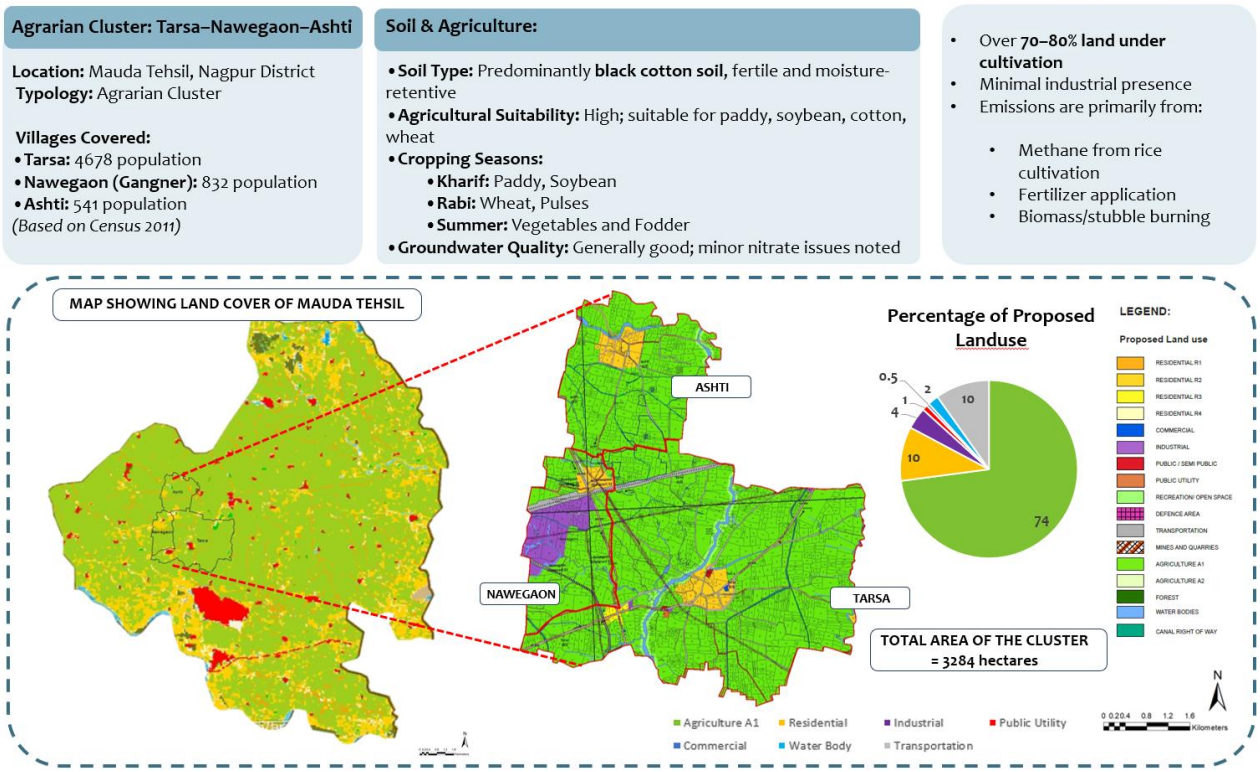


Figure 3.4 Spatial and Functional Profile of the Agrarian Village Cluster (Tarsa-Nawegaon-Ashti)

Situated in Mauda Tehsil of Nagpur District, the villages of Tarse, Nawegaon (Gangner), and Ashti collectively form an agrarian cluster characterized by intensive agricultural activity and limited industrial influence. According to the 2011 Census, these villages have populations of approximately 4,678 in Tarsa, 832 in Nawegaon, and 541 in Ashti, respectively (Government of India, 2011).

The cluster is predominantly covered by black cotton soil, known for its fertility and excellent moisture retention capacity, making the area highly conducive to crop cultivation. The land use is largely agricultural, with 70 to 80 percent of the area under cultivation, emphasizing its primary economic base.

The region supports multiple cropping seasons, reflecting a diversified and robust agricultural calendar:

- Kharif season is dominated by crops such as paddy and soybean.
- Rabi season features the cultivation of wheat and pulses.
- During the summer months, farmers primarily grow vegetables and fodder crops.

This diversified cropping system takes advantage of the soil's fertility and supports food security and livelihood for the local population.

Groundwater quality across the cluster is generally favorable, although minor concerns regarding nitrate contamination have been identified, necessitating monitoring and sustainable water

management (Central Ground Water Board., Groundwater quality status report. Ministry of Water Resources, Government of India). Greenhouse gas emissions in this agrarian context mainly arise from agricultural activities. The Key sources include:

- Methane emissions associated with flooded rice paddies.
- Emissions from fertilizer application, particularly nitrous oxide.
- Release of pollutants due to biomass and stubble burning, which remains a prevalent post-harvest practice in the region.
- character, presenting opportunities for sustainable rural development focused on improving agricultural efficiency and reducing emissions.

Chapter -4
EMISSION INVENTORY

4.1 Scope 1 Emissions

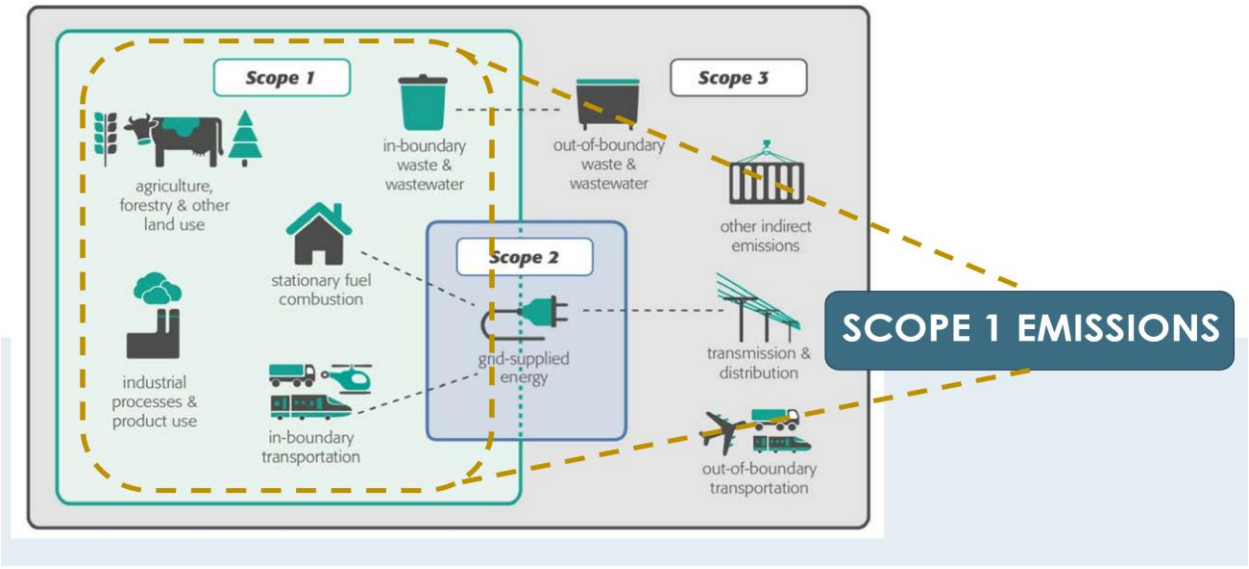


Figure 4.1 Classification of Scope 1 emissions

4.1.1 Livestock Emissions

Greenhouse gas (GHG) emissions from livestock constitute a major portion of total agricultural emissions, especially in regions where animal farming forms a central pillar of the economy. Accurate quantification of these emissions is critical for understanding their contribution to climate change and for developing appropriate mitigation strategies. In this study, livestock-related methane emissions were estimated using the Tier 1 methodology prescribed by the Intergovernmental Panel on Climate Change (IPCC) in its 2006 guidelines for national GHG inventories (IPCC, 2006).

This method is particularly suitable when region-specific emission factors are unavailable, offering a practical yet standardized approach to emissions estimation.

Animal population data for species such as cattle, buffaloes, goats, and other domesticated livestock were compiled through a combination of localized field surveys and reliable secondary data sources. These data inputs were used to compute methane (CH_4) emissions resulting from enteric fermentation and manure management practices.

The estimation was performed using the following formula, where emissions are calculated in kilograms per year:

CH_4 Emissions (kg/year) = Number of Animals × Emission Factor (kg/animal/year)

To enhance clarity and ensure consistency with standard reporting formats, the total methane emissions were subsequently converted from kilograms to metric tons using the standard conversion factor: **1,000 kg = 1 ton**

However, since different greenhouse gases exhibit varying levels of heat-trapping potential in the atmosphere, a conversion to carbon dioxide equivalent (CO_2e) was essential to enable effective comparison and aggregation. The Global Warming Potential (GWP) is a metric used for this purpose, allowing for the comparison of the long-term climate impacts of various gases relative to carbon dioxide. According to the Fifth Assessment Report (AR5) of the IPCC, the GWP of methane over a 100-year time horizon is 28 (IPCC, 2014).

Accordingly, the methane emissions in tons were converted to CO_2 equivalents using the following equation:

CO_2e (tons) = CH_4 Emissions (tons) × 28

This conversion provides a unified framework for evaluating emissions across various sectors and supports integration into national and international climate reporting obligations.

Table 4.1 Direct GHG Emissions from Enteric Fermentation

Cluster	Cows (Nos.)	Buffaloes (Nos.)	Goats (Nos.)	Others (Nos.)	Total CH_4 Emissions (tons/year)	Total CO_2e Emissions (tons/year)
Kadoli-Asoli-Mahalgaon (MIXED)	130	200	240	150	19.50	**546.00**
Tarsa-Nawegaon-Ashti (AGRARIAN)	180	270	300	150	26.40	**739.20**
Kirmiti Cluster (INDUSTRIAL)	20	22	50	60	2.62	**73.36**

Table 4.2 Methane Emission Factor (IPCC)

Animal Type	Methane Emission Factor
Cow	55 kg CH_4/head/year
Buffalo	55 kg CH_4/head/year
Goat	5 kg CH_4/head/year
Others (assumed)	1 kg CH_4/head/year

4.1.2 Emissions from Waste Disposal (IPCC Tier 1 Method)

This section presents Scope 1 greenhouse gas emissions from municipal solid waste disposal in rural village clusters, calculated using the **IPCC Tier 1 methodology**. These emissions result from the **anaerobic decomposition** of organic waste under open dumping conditions, which leads to **methane (CH_4) generation**. The total emissions are expressed in **CO_2 equivalent (CO_2e)** using a global warming potential (GWP) value of 28 for CH_4, as per IPCC AR5 standards.

The formula used for CH_4 generation is:

$$\mathbf{CH_4 = Waste \times MCF \times DOC \times DOCF \times F \times 16/12},$$

followed by conversion to CO_2 equivalent using

$$\mathbf{CO_2e = CH_4 \times GWP\ of\ CH_4\ (28)}.$$

Key parameters used in the calculation include:

- **Waste generation** (tons/year): calculated based on population × 0.35 kg/person/day × 365 ÷ 1000.
- **MCF** (Methane Correction Factor) = 0.6 (IPCC default for open dumping in rural areas).
- **DOC** (Degradable Organic Carbon) = 0.15.
- **DOCF** (Fraction of DOC decomposing anaerobically) = 0.5.
- **F** (Fraction of landfill gas that is CH_4) = 0.5.
- **16/12**: Molecular weight conversion ratio (carbon to methane) = 1.33.
- **GWP of CH_4** = 28.

Table 4.3 Emissions from Waste Disposal

Cluster	Village	Population (2025)	Waste Treatment	Emissions (tCO_2e/year)	Cluster Total (tCO_2e/year)
🌾 **Agrarian**	Tarsa	5,370	100% Dumped / 0% Composted	576.25	**774.24**
	Nawegaon-Ashti	1,845	100% Dumped / 0% Composted	197.99	
🌿 **Mixed Typology**	Kadoli	2,314	100% Dumped / 0% Composted	248.32	**471.95**
	Asoli	1,360	50% Dumped / 50% Composted	72.97	
	Mahalgaon	2,808	50% Dumped / 50% Composted	150.66	
🏭 **Industrial**	Kirmiti Cluster (5 villages)	5,881	50% Dumped / 50% Composted	631.10	**631.10**

Table 4.4 Default IPCC standards for Waste Emissions

Parameter	Value	Meaning
Waste	Annual waste generated (tons)	Calculated from population × 0.35 kg/person/day × 365 ÷ 1000
MCF	0.6	Methane Correction Factor for open dumping (IPCC default for rural conditions)
DOC	0.15 (15%)	Degradable Organic Carbon — organic fraction of waste
DOCF	0.5	Fraction of DOC that decomposes anaerobically
F	0.5	Fraction of landfill gas that is CH_4
16/12	1.33	Converts carbon to methane (molecular weight ratio)

4.1.3 Agriculture Emissions (Fertilizers, Paddy Methane)

Agricultural waste emissions, particularly those resulting from fertilizer use and crop residue management, represent a substantial source of greenhouse gases (GHGs) in rural farming systems. In this context, emissions were estimated using a systematic multi-step approach, drawing upon both regional agricultural practices and globally recognized guidelines. The methodology was rooted in the IPCC Tier 1 framework, which is designed for standardized GHG inventory reporting when location-specific emission factors are not available (IPCC, 2006). Cropland was subdivided into two major categories based on cropping patterns. The first category comprised areas under rice–wheat rotation systems, where paddy is cultivated during the Kharif (monsoon) season and wheat during the Rabi (winter) season. The second category included areas under other crops such as soybean, chickpea (channa), cotton, and chilli, which do not follow the rice–wheat sequence but are nonetheless major contributors to agricultural output and fertilizer consumption in the region.'

Step 1: Area Classification

Table 4.5 Area Classification for the Agriculture land

Cluster	Total Agriculture Area (ha)	Rice–Wheat Area (ha)	Other Crops Area (ha)
Tarsa-Nawegaon-Ashti (Agrarian)	2600	2000	600
Kadoli-Asoli-Mahalgaon (Mixed)	816	490	326
Kirmiti Cluster (Industrial)	320	192	128

Step 2: Emission Sources Considered

Table 4.6 Emission Sources considered for agricultural Emission

Crop/Activity	Gas Emitted	Type of Emission
Rice Cultivation (Kharif Season)	Methane (CH_4)	From anaerobic decomposition in flooded rice paddies
Wheat Cultivation (Rabi Season)	Nitrous Oxide (N_2O)	From nitrogen fertilizer application
Other Crops (Soyabean, Channa, etc.)	Nitrous Oxide (N_2O)	From nitrogen fertilizer application

Step 3: Methane Emissions Calculation (from Rice)

Methane (CH_4) emissions from rice fields represent a significant source of greenhouse gases in agrarian regions, particularly under flooded conditions typical of traditional paddy cultivation. These emissions are estimated using the IPCC 2006 Tier 1 methodology, which provides a default emission factor for methane release from paddy fields.

According to IPCC guidelines, the default CH_4 emission factor is 1.30 tons of CH_4 per hectare per season. This factor assumes continuous flooding and conventional farming practices without specific mitigation measures. The emissions are calculated using the following formula:

CH_4 Emissions (tons/year) = Rice Area (ha) × 1.30

This simple, activity-based formula allows for rapid estimation of annual methane emissions from rice cultivation using known data on the total area under paddy. The method is especially useful in data-scarce rural contexts and provides a conservative baseline for carbon accounting in agricultural sectors.

Step 4: Estimating Nitrous Oxide Emissions from Fertilizer Use

A critical source of nitrous oxide (N_2O)—a potent greenhouse gas—arises from nitrogen-based fertilizers. Assumptions regarding fertilizer application rates were made based on common agricultural practices observed in Vidarbha's rural landscape. It was estimated that wheat crops receive approximately 100 kilograms of nitrogen per hectare, while the other crops listed receive around 40 kilograms of nitrogen per hectare.

The emissions were calculated using the default emission factor provided in the IPCC Tier 1 guidelines, which assumes that 1% of the total nitrogen applied to soils is emitted directly as N_2O:

Direct N_2O Emissions (kg/year) = Total Nitrogen Applied (kg/year) × 0.01

Step 5: Unit Conversion to Metric Tons

To ensure consistency and to facilitate comparison with emissions from other sectors and gases, both methane (CH_4) and nitrous oxide (N_2O) emissions were converted from kilograms to metric tons using the standard conversion factor:

1,000 kg = 1 ton

This step standardizes reporting, making it compatible with broader climate reporting frameworks and policy evaluation tools.

Step 6: Conversion to Carbon Dioxide Equivalent (CO_2e)

Since different greenhouse gases have varying impacts on global warming, emissions were further converted into carbon dioxide equivalents (CO_2e) using their respective Global Warming Potentials (GWPs). According to the IPCC's Fifth Assessment Report (AR5), the GWP for

methane is 28, while the GWP for nitrous oxide is significantly higher at 265 (IPCC, 2014). The conversion allows for aggregation of emissions and simplifies the assessment of total climate impact:

$$\mathbf{CH_4\ CO_2e\ (tons) = CH_4\ emissions\ (tons) \times 28}$$

$$\mathbf{N_2O\ CO_2e\ (tons) = N_2O\ emissions\ (tons) \times 265}$$

This process of GWP-based standardization is critical in enabling policymakers and researchers to compare emissions across gases and sectors using a unified metric, facilitating more informed climate action planning and mitigation strategy development. (IPCC, 2014).

Cluster wise Agricultural Emissions from Rice Cultivation and Fertilizer

Agricultural greenhouse gas (GHG) emissions were quantified by assessing methane (CH_4) outputs from paddy fields during the Kharif season and nitrous oxide (N_2O) emissions linked to fertilizer application across both Rabi and Kharif seasons. The estimation process adhered to the Intergovernmental Panel on Climate Change (IPCC) 2006 Tier 1 methodology, utilizing standard emission factors and global warming potential (GWP) values—28 for CH_4 and 265 for N_2O (IPCC, 2006).

Table 4.7 Cluster-wise Agricultural Emissions from Rice Cultivation and Fertilizer Use (IPCC Tier 1 Estimates)

Cluster	Rice Area (ha)	Other Crops Area (ha)	CH_4 Emissions from Rice (tons/year)	N_2O Emissions from Fertilizer (tons/year)	CH_4 Emissions (CO_2e tons/year)	N_2O Emissions (CO_2e tons/year)	Total Agriculture Emissions (CO_2e tons/year)
Agrarian Cluster	2000	600	2600.0	2.2400	72,800.0	593.60	**73,393.60**
Mixed Cluster	490	326	637.0	0.6204	17,836.0	164.41	**18,000.41**
Industrial Cluster	192	128	249.6	0.2432	6,988.8	64.45	**7,053.25**

Table 4.8 IPCC Tier 1 and Standard Agricultural Emission Assumptions

Parameter	Value
CH_4 emission factor for rice	1.30 tons CH_4/ha/season
Nitrogen fertilizer use (Wheat)	100 kg N/ha
Nitrogen fertilizer use (Soyabean/Chana etc.)	40 kg N/ha
Direct N_2O emission factor	1% of N applied
GWP of CH_4	28
GWP of N_2O	265

Among the surveyed regions, the agrarian zone comprising Tarsa, Nawegaon, and Ashti exhibited the highest GHG emissions from agriculture. This predominance is attributed to the extensive cultivation of rice, which significantly elevates CH_4 levels due to anaerobic decomposition in flooded fields. Fertilizer application contributed to emissions on a secondary scale, primarily through the release of N_2O.

In contrast, mixed-use and industrial clusters reported lower emissions. The disparity is largely due to the limited area under paddy cultivation in these regions compared to the Tarsa-Nawegaon-Ashti cluster, where rice farming is more intensive.

4.1.4 Stubble burning

After the harvest of major seasonal crops—primarily rice in the Kharif season and wheat in the Rabi season—farmers often resort to open-field burning of leftover crop residues (stubble) to rapidly clear land for subsequent planting cycles. This widespread practice results in the emission of several atmospheric pollutants, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), particulate matter (PM2.5), carbon monoxide (CO), volatile organic compounds (VOCs), and smoke.

According to the Intergovernmental Panel on Climate Change (IPCC) 2006 Guidelines (IPCC, 2006), CO_2 emissions from the burning of agricultural residues are regarded as carbon neutral in greenhouse gas (GHG) inventories. This classification is based on the principle that the CO_2 released during combustion was previously sequestered from the atmosphere during the plant's growth cycle, leading to no net addition of CO_2 to the atmosphere (IPCC, 2006). Therefore, only non-CO_2 gases—specifically CH_4 and N_2O—are included in national GHG accounts under Scope 1 direct emissions.

However, from an air quality and environmental health perspective, the implications of stubble burning are severe. Although CO_2 is excluded from climate inventories, the act of burning releases substantial quantities of PM2.5, CO, and other toxic pollutants, which significantly degrade air quality, particularly during post-harvest months. These emissions contribute to reduced visibility, respiratory ailments, and broader environmental degradation. Thus, while the climate accounting framework considers CO_2 from biomass burning neutral, the environmental consequences of this practice remain critically important and demand policy intervention under pollution control and public health frameworks.

Emissions from Stubble Burning (Rice and Wheat)

Following the harvest of rice (Kharif season) and wheat (Rabi season), it is a widespread practice in rural Maharashtra to burn leftover plant biomass—commonly referred to as stubble—in open fields. This process releases various pollutants, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and particulate matter ($PM_{2.5}$). While CO_2 from biomass burning is considered carbon neutral under IPCC guidelines, CH_4 and N_2O emissions are treated as net greenhouse gas (GHG) emissions and must be included in emission inventories.

The emissions are estimated using the IPCC 2006 Tier 1 methodology as follows:

Step 1: IPCC Formula for Estimating Emissions from Stubble Burning

Emission (kg gas) = Crop Production × RPR × Dry Matter Fraction × Fraction Burnt × Combustion Efficiency × Emission Factor

Table 4.9 Values and assumptions (Standard IPCC + India Studies) for Stubble burning

Parameter	Rice	Wheat
Residue-to-Product Ratio (RPR)	1.2	1.5
Dry Matter Fraction	0.8	0.85
Fraction Burnt on Field	0.25 (conservative)	0.25
Combustion Efficiency	0.9	0.9
Emission Factor CH_4	2.7 kg/ton dry matter	2.7 kg/ton dry matter
Emission Factor N_2O	0.07 kg/ton dry matter	0.07 kg/ton dry matter

Step 2 : Estimating Crop Production

To estimate total biomass residue, the production of rice and wheat must first be calculated using average yield values typical of rural Maharashtra:

Table 4.10 Estimation of crop Production to estimate biomass residue

Crop	Assumed Yield (tons/hectare)
Rice	3.5 tons/ha
Wheat	3.0 tons/ha

Step 3 : Convert to CO_2-Equivalent (CO_2e)

Finally, methane and nitrous oxide emissions are converted into CO_2e using their respective global warming potentials (GWP):

$$\mathbf{CH_4 \text{ emissions } (CO_2e) = CH_4 \times 28}$$

$$\mathbf{N_2O \text{ emissions } (CO_2e) = N_2O \times 265}$$

This step-wise methodology provides a standardized, science-based approach to estimating GHG emissions from agricultural residue burning. It is critical for understanding rural emission hotspots and for designing low-carbon agricultural interventions in alignment with India's climate mitigation goals.

Table 4.11 Estimation of Carbon Emissions from Stubble Burning

Cluster	Rice Area (ha)	Other Area(ha)	CH_4 Emissions (tons/year)	N_2O Emissions (tons/year)	CH_4 Emission CO_2e tons/year	N_2O Emission CO_2e tons/year	Total Stubble Burning CO_2e tons/year
(Agrarian Cluster)	2000	600	8.73	0.23	244.43	59.98	**304.41**
(Mixed Cluster)	490	326	2.14	0.06	59.89	14.69	**74.58**
(Industrial Cluster)	192	128	0.84	0.02	23.47	5.76	**29.22**

4.1.5 Stationary Fuel Combustion (LPG, Diesel)

Stationary combustion emissions arise from the use of cooking fuels (LPG, biogas) in households and diesel generators in industries. This section outlines the stepwise methodology used to estimate these emissions for each village cluster, based on field data, IPCC 2006 Tier 1 default emission factors, and rural energy use assumptions.

Step 1: Identify Fuel Use Sources

Households in rural clusters primarily use LPG for cooking, with limited biogas adoption. Industries, including rice mills, cement plants, and small manufacturing units, rely on diesel generators for power backup. These fuel sources were identified based on household surveys and Gram Panchayat records.

Step 2: Data Collection and Estimation

Cluster-wise household and industry counts were recorded, along with fuel use type. The table below shows the data collected for each sector:

Table 4.12 Simple Cluster- wise Data summary for stationary combustion emissions

Sector	Data Collected
Households (Cooking Fuel)	Number of households per cluster; % using LPG or Biogas
Industries (Diesel Use)	Number of industries per cluster; standard diesel consumption assumption for small industries

Step 3: Fuel Consumption Assumptions (Standardized)

Standardized assumptions were applied based on national surveys and technical reports:

Table 4.13 Simple Cluster- wise Data summary for stationary combustion emissions

Fuel	Assumption Used	Source of Assumption
LPG for Households	12 cylinders/year per household (~144 kg/year)	MNRE & MoPNG rural LPG usage studies
Diesel use in small industries	3000 liters/year per industry	SME energy use surveys (TERI, CII, BEE reports)
Diesel use in rice mills	5000 liters/year per mill	IPCC 2006 + FAO studies on rice processing
Diesel use in cement plant	10000 liters/year	Conservative assumption based on auxiliary diesel needs

Step 4: Convert Fuel Use to Energy (GJ)

Fuel quantities were converted to energy in GigaJoules using calorific values:

Table 4.14 Simple Cluster- wise Data summary for stationary combustion emissions

Fuel	Energy Content
LPG	46.1 MJ/kg
Diesel	38.6 MJ/litre

Step 5: Apply Emission Factors (IPCC Tier 1 Defaults)

The following IPCC emission factors were used for fuel combustion:

Table 4.15 Simple Cluster- wise Data summary for stationary combustion emissions

Fuel	CO_2 (kg/GJ)	CH_4 (kg/GJ)	N_2O (kg/GJ)
LPG	63.1	0.001	0.0001
Diesel	74.1	0.003	0.0006

Step 6: Calculate Emissions

To estimate stationary combustion emissions, the first step involved calculating the **energy content of fuel consumed**, separately for **LPG used in households** and **diesel used in industrial operations**. The LPG energy consumption was computed using the formula:

LPG Energy (GJ) = Number of households × 144 kg/year × 46.1 MJ/kg ÷ 1000

Here, 144 kg represents the annual LPG consumption per household (equivalent to 12 standard cylinders), and 46.1 MJ/kg is the calorific value of LPG. The final value was converted to gigajoules (GJ) by dividing by 1000.

For diesel, energy consumption was calculated based on the assumed annual diesel usage per industry and the fuel's energy content. The formula used was:

Diesel Energy (GJ) = Number of industries × Diesel usage (litres/year) × 38.6 MJ/litre ÷ 1000

In this case, 38.6 MJ/litre is the calorific value of diesel, and standard diesel usage assumptions (e.g., 3000 litres/year per SME, 5000 litres/year for rice mills, 10,000 litres/year for cement plants) were applied depending on the type of industry in each cluster.

Once total energy consumption in GJ was derived for both LPG and diesel, the next step was to calculate emissions. This was done using the basic emission formula:

Emissions (kg) = Energy (GJ) × Emission Factor (kg/GJ)

This formula was applied individually for each gas—carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)—using their respective IPCC Tier 1 default emission factors. CO_2 emissions were directly added as tons, whereas CH_4 and N_2O emissions, although small in quantity, were converted into CO_2-equivalents (CO_2e) using their global warming potentials (GWPs): 28 for CH_4 and 265 for N_2O. This detailed and stepwise computation ensured an accurate estimation of stationary emissions for each village cluster and fuel type.

Step 7: Convert CH_4 and N_2O to CO_2-equivalent

Following the estimation of individual greenhouse gas emissions, non-CO_2 gases—namely methane (CH_4) and nitrous oxide (N_2O)—were converted into carbon dioxide equivalents (CO_2e) using their respective Global Warming Potentials (GWPs), as prescribed by the IPCC 2006 Tier 1 methodology. This step ensures that all emissions are expressed in a standardized unit of CO_2e for comparability and aggregation. The conversion was performed using the following multipliers:

CH_4 emissions were multiplied by a GWP of 28, reflecting its global warming impact over a 100-year time horizon. N_2O emissions were multiplied by a GWP of 265, given its significantly higher radiative forcing. CO_2 emissions, being the reference greenhouse gas, were directly reported in metric tons without conversion. The sum of CO_2, CH_4 (as CO_2e), and N_2O (as CO_2e) provided the total stationary combustion emissions in CO_2-equivalent terms for each cluster.

Stationary fuel combustion emissions were assessed for three clusters—Kadoli–Asoli–Mahalgaon (Mixed Cluster), Tarsa–Nawegaon–Ashti (Agrarian Cluster), and Kirmiti–Tembhari–Wateghat–Turkmari–Kinhi (Industrial Cluster). These emissions primarily arise from the use of LPG in households for cooking and diesel generators in industries. The calculations are based on household survey data and industry counts, with emissions estimated using IPCC 2006 Tier 1 default emission factors and standardized assumptions for fuel usage.

Fuel usage assumptions include 144 kg LPG per household annually, 3000 litres of diesel per industry per year, 5000 litres per rice mill, and 10,000 litres per cement plant. Fuel consumption was converted to energy using standard calorific values (46.1 MJ/kg for LPG and 38.6 MJ/litre for diesel). Emissions were calculated using the IPCC's default emission factors and converted to CO_2-equivalents using global warming potentials (GWP) of 28 for CH_4 and 265 for N_2O.

Table 4.16 Stationary Combustion Emission Summary for Village Clusters

Cluster	Households	Cooking Fuel	Industries	Industrial Fuel Use
Mixed Cluster	1127 households	3 Biogas users, rest LPG	120 industries (Steel, Food, Engineering, Tools)	Diesel: 3000 liters/year per industry
Agrarian Cluster	1647 households (1030 in Tarsa + 617 in Nawegaon/Ashti)	100% LPG	5 Rice mills + 1 UltraTech Cement Plant	Diesel: 5000 liters/year per rice mill, 10000 liters/year for cement plant
Industrial Cluster	1034 households	100% LPG	134 industries (various types, detailed list given)	Diesel: 3000 liters/year per industry

Table 4.17 Estimation of Carbon Emissions from Stationary Fuel Combustion

Cluster	LPG Energy Consumption (GJ)	Diesel Energy Consumption (GJ)	Total CO_2 Emissions (tons/year)	Total CH_4 Emission (tons CO_2e/year)	Total N_2O Emissions (tons CO_2e/year)	Total Stationary Emissions (tons CO_2e/year)
Mixed Cluster	7481.48	13896.0	1501.77	1.38	2.41	**1505.56**
Agrarian Cluster	10933.44	1351.0	790.01	0.42	0.50	**790.93**
Industrial Cluster	6864.11	15517.2	1582.95	1.50	2.65	**1587.09**

4.1.6 Mobility Fuel Combustion Emissions

This section presents the methodology and findings for calculating Scope 1 greenhouse gas (GHG) emissions from transport activities in three rural clusters: Kadoli–Asoli–Mahalgaon (Mixed Cluster), Tarsa–Nawegaon–Ashti (Agrarian Cluster), and Kirmiti–Tembhari–Turkmari–Wateghat–Kinhi (Industrial Cluster). The assessment focuses on two-wheelers, cars, and tractors, which are the dominant modes of transportation in rural Maharashtra.

Step 1: Base Data and Work Pattern Assumptions

The male population and occupational distribution formed the basis for estimating vehicle ownership and travel behavior. The classification of occupational categories (agriculture, local industry, and commuting to urban areas) was derived from census data, field surveys, and Panchayat consultations.

Cluster	Male Population (2011)	Assumed Work Pattern	Households
Kadoli-Asoli-Mahalgaon	2949 males	5% commute to Nagpur, 50% work in nearby industries, 45% agriculture	1127 households
Tarsa-Nawegaon-Ashti	3198 males	20% work in industries, 80% agriculture	700 households (450+250 assumed)
Kirmiti Cluster	2900 males	90% work in nearby industries, 10% agriculture	1034 households

Table 4.18 Base data and Work pattern Assumptions

Step 2: Vehicle Estimation

Vehicle ownership was estimated based on rural transport norms:

- **Two-wheelers:** 1 for every 2 working males
- **Cars:** 1 per 20–30–15 households (cluster-dependent)
- **Tractors:** 1 for every 12 farming households

Table 4.19 Vehicle Estimation

Cluster	Estimated Two-Wheelers	Estimated Cars	Estimated Tractors
Kadoli-Asoli-Mahalgaon	**1475**	**56**	**20**
Tarsa-Nawegaon-Ashti	**1599**	**23**	**43**
Kirmiti Cluster	**1450**	**69**	**5**

Step 3: Fuel and Distance Assumptions

Fuel efficiency and travel distance assumptions were drawn from rural transport behavior in Maharashtra:

Table 4.20 Fuel Asuumptions (Standard Rural India)

Vehicle Type	Mileage	Annual Distance Travelled
Two-Wheelers (Petrol)	40 km/litre	10,000 km/year
Cars (Petrol)	14 km/litre	12,000 km/year
Tractors (Diesel)	6 km/liter	4,000 km/year

Distance variation reflects differences in occupational patterns—agriculture trips are local (~2–5 km), while industrial workers and commuters travel longer distances (~5–20 km one way). Fuel consumption for each vehicle type was calculated using the formula:

$$\textbf{Fuel Consumed (litres/year)} = \left(\frac{\text{Annual Distance (km/year)}}{\text{Mileage (km/litre)}}\right) \times \text{Number of Vehicles}$$

Step 4 : Assigning Annual Distance Travelled

Table 4.21 Assigning Annual Distance Travelled

Cluster	Two-Wheeler Annual Distance	Reason
Kadoli Cluster	7500 km/year	20% commute to Nagpur (~15–20 km one way), 40% nearby industries, 40% agriculture – longer average trips
Tarsa Cluster	10,000 km/year	Mostly short field-to-market trips (local agriculture)
Kirmiti Cluster	10,000 km/year	Industrial work commuting (~5–10 km one way)

Step 5: Emission Estimation Using IPCC Factors

GHG emissions were estimated using **IPCC 2006 Tier 1 default emission factors** for petrol and diesel fuels:

Table 4.22 Emission Factors Applied (IPCC 2006)

Fuel	CO_2 Emission	CH_4 Emission	N_2O Emission
Petrol	2.32 kg CO_2/litre	0.0002 kg CH_4/litre	0.00008 kg N_2O/litre
Diesel	2.68 kg CO_2/litre	0.0001 kg CH_4/litre	0.00006 kg N_2O/litre

Emissions for each gas were calculated as:

$$\textbf{Emissions (kg/year)} = \text{Fuel Consumed (litres/year)} \times \text{Emission Factor (kg/litre)}$$

Step 6: Conversion to CO_2-equivalents

Methane (CH_4) and nitrous oxide (N_2O) emissions were converted into **CO_2-equivalents (CO_2e)** using their **Global Warming Potentials (GWPs)**:

- **$CH_4 \times 28$**
- **$N_2O \times 265$**

Final emissions were reported as

$$\textbf{Total Emissions (tons } CO_2e\textbf{/year)} = CO_2 \text{ (tons)} + (CH_4 \text{ (tons)} \times 28) + (N_2O \text{ (tons)} \times 265)$$

Step 7: Final Results and Cluster-Wise Emission Comparison

Table 4.23 Final Clusterwise Mobility Emission

Cluster	Final Mobility Emissions (tons CO_2e/year)	Key Reasons / Justification
Kadoli-Asoli-Mahalgaon (Mixed Cluster)	**797.67**	-5% males commute long distances (~15–20 km one way) to Nagpur city. - 50% work in nearby industries (~5–10 km one way). - 45% agriculture locally (~2–5 km). Corrected weighted annual distance for two-wheelers = 7500 km/year. Fuel consumption adjusted accordingly. Hence mobility emissions are high but lower than pure agricultural cluster because of trip distribution.
Tarsa-Nawegaon-Ashti (Agrarian Cluster)	**1019.77**	80% people engaged in agriculture. Daily short trips between fields and local markets (~2–5 km per trip). 20% work in nearby small industries. Higher number of tractors in agriculture sector. Two-wheelers assumed to travel 10,000 km/year. Tractor diesel use majorly contributes to emissions. Hence Tarsa has highest mobility emissions overall.
Kirmiti-Tembhari-Turkmari-Wateghat-Kinhi (Industrial Cluster)	**869.62**	90% of workers are employed in local industries. Short to medium two-wheeler commutes (~5–10 km one way). Only 10% involved in agriculture (low tractor usage). Two-wheelers assumed 10,000 km/year. Very few tractors compared to agrarian areas. Hence mobility emissions are lower than Tarsa, slightly higher than corrected Kadoli.

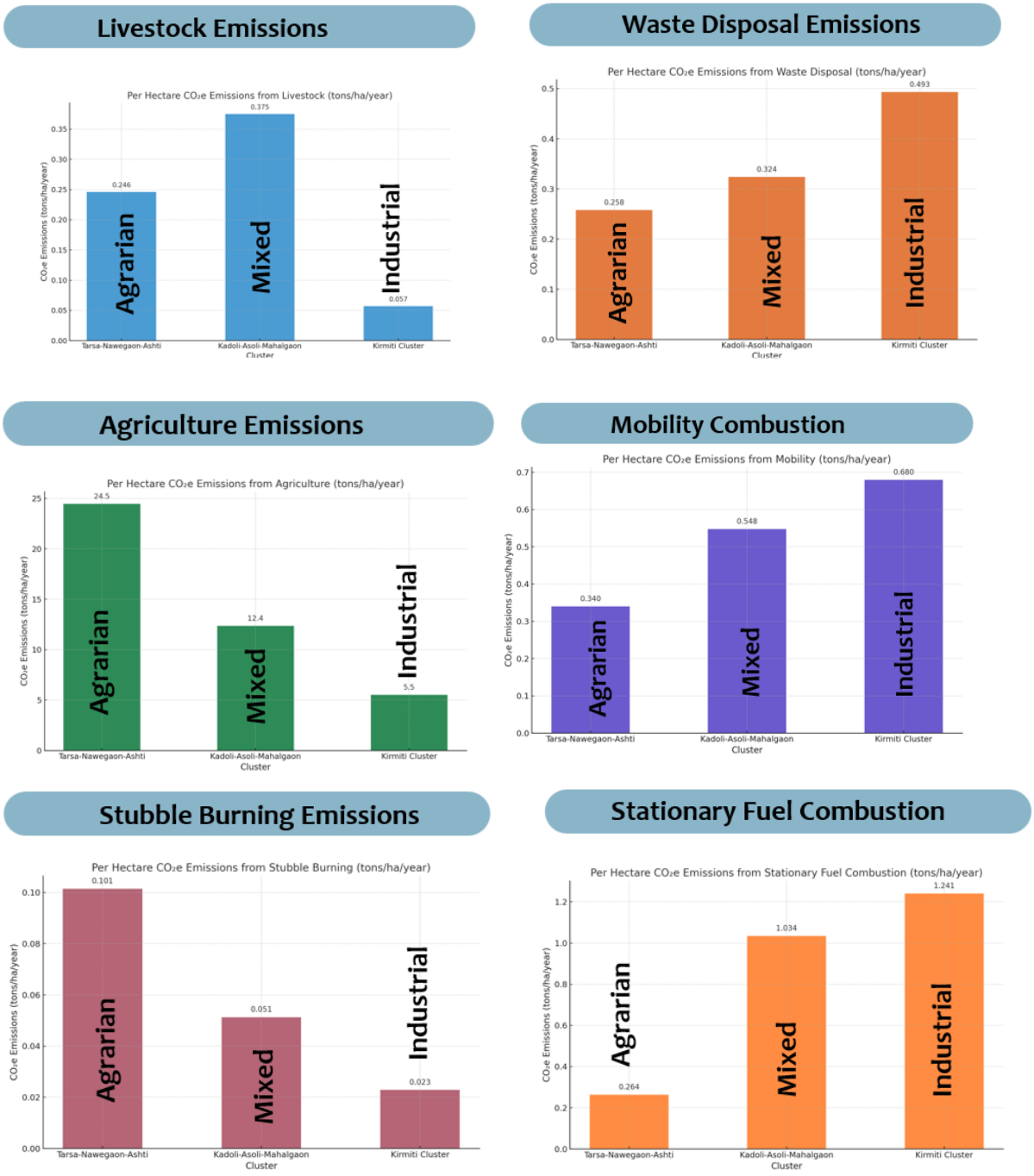


Figure 4.2 Graph showing Clusterwise Scope 1 Emission

Note: All emission values across the graphs are represented on a per hectare basis to allow for uniform comparison across clusters. Since each cluster varies significantly in both total area and population, this standardization enables a fair assessment of emission intensity and helps identify typology-based emission drivers irrespective of geographic size.

A comprehensive assessment of Scope 1 greenhouse gas (GHG) emissions was conducted for each of the three study clusters—Kadoli–Asoli–Mahalgaon (Mixed Cluster), Tarsa–Nawegaon–Ashti (Agrarian Cluster), and Kirmiti Cluster (Industrial Cluster)—based on all major direct emission sources. These included emissions from agriculture, livestock, stubble burning, waste disposal, stationary combustion (cooking and industry), and mobility.

The Agrarian Cluster recorded the highest overall Scope 1 emissions, primarily driven by large-scale paddy cultivation and associated methane emissions. The Mixed Cluster followed, with moderate emissions from all sectors due to its balanced land-use character. The Industrial Cluster, despite its high number of industrial units, reported the lowest total Scope 1 emissions due to limited agricultural activity and smaller spatial extent.

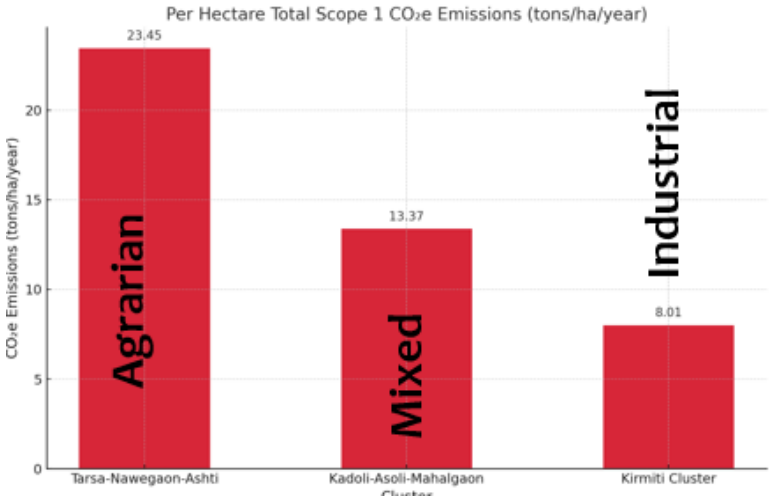
Table 4.24 Scope 1 Emissions by Cluster and Sector (in tCO_2e/year)

Cluster	Livestock	Agriculture	Stubble Burning	Waste	Stationary Combustion	Mobility	Total Scope 1 Emissions
Kadoli–Asoli–Mahalgaon (Mixed)	546.00	18,000.41	74.58	471.95	1,505.56	797.67	21,396.17
Tarsa–Nawegaon–Ashti (Agrarian)	739.20	73,393.60	304.41	774.24	790.93	1,019.77	77,022.15
Kirmiti Cluster (Industrial)	73.36	7,053.25	29.22	631.10	1,587.09	869.62	10,243.64

To assess land-use intensity of emissions, total emissions were normalized by each cluster's spatial extent. The Agrarian Cluster exhibited the highest land-based emission pressure due to its expansive agricultural land and intensive paddy cultivation. The Industrial Cluster, with lower agricultural land, showed the least per hectare emission intensity.(Refer Table No 4.25)

Table 4.25 Per Hectare Scope 1 Emissions

Cluster	Total Emissions (tCO_2e/year)	Area (ha)	Per Hectare Emissions (tCO_2e/ha/year)
Kadoli–Asoli–Mahalgaon (Mixed)	21,396.17	1,600	13.37
Tarsa–Nawegaon–Ashti (Agrarian)	77,022.15	3,284	**23.46**
Kirmiti Cluster (Industrial)	10,243.64	1,279	8.01



Tarsa–Nawegaon–Ashti as the highest emitter (23.46 tCO_2e/ha/year)

Kadoli–Asoli–Mahalgaon in the middle (13.37 tCO_2e/ha/year)

Kirmiti Cluster as the lowest (8.01 tCO_2e/ha/year)

Figure 4.3 Per Hectare Scope 1 Emissions

This confirms the strong impact of agriculture, especially rice cultivation, in driving up emission intensity in rural regions.

4.2 Scope 2 Emissions: Estimation from Electricity Use

Scope 2 emissions refer to indirect greenhouse gas (GHG) emissions that result from the consumption of purchased electricity. In the context of rural clusters, these emissions are particularly significant across sectors such as household consumption, agricultural irrigation, street lighting, public services, and industrial operations. These emissions are accounted for under India's national carbon inventory using the **Central Electricity Authority (CEA) 2023 default emission factor**, which is:

Emission Factor (EF)= 0.82 kg CO_2/kWh X Emission Factor (EF)

The general formula applied to estimate Scope 2 emissions is:

$$\textbf{Scope 2 Emissions (tons } CO_2\textbf{/year)} = \frac{\text{Electricity Consumed (kWh/year)} \times 0.82}{1000}$$

Step 1 : Baseline Data for Scope 2 Emission Estimation

Each cluster's electricity consumption was estimated using sector-specific data, such as number of households, streetlights, public institutions, agricultural land, and number/type of industries. These values serve as the foundation for sector-wise electricity use calculations.

Cluster	Households	Streetlights	Public Buildings	Agricultural Land (ha)	Industries
Kadoli-Asoli-Mahalgaon	1300	173	~9	1600	120
Tarsa-Nawegaon-Ashti	1647	525	~12	3284	5 Rice Mills + 1 Cement
Kirmiti Cluster	2034	760	~10	1279	131

Table 4.26 Baseline Data for Scope 2 Emission Estimation

Step 2: Stepwise Sectoral Electricity Use Calculations

A. Household Electricity Consumption

Household electricity usage is estimated using the assumption of **1800 kWh/year per household**, based on rural consumption benchmarks.

Table 4.27 Household Electricity Consumption

Cluster	Households	Electricity Use (kWh/year)
Kadoli	1300	2,340,000
Tarsa	1647	2,964,600
Kirmiti	2034	3,661,200

B. Streetlight Electricity Consumption

Assuming each streetlight is **40W**, operating **12 hours/day for 365 days/year**, the annual electricity use is:

$$\text{Annual per light use} = 40W \times 12 \text{ hrs} \times 365 = 175.2 \text{ kWh/light/year}$$

$$\text{Total Consumption} = \text{No. of Lights} \times 175.2$$

Table 4.28 Streetlight Electricity Consumption

Cluster	Streetlights	Electricity Use (kWh/year)
Kadoli	173	30,310
Tarsa	525	91,980
Kirmiti	760	133,152

C. Public Building Electricity Consumption

Estimated using average monthly bills divided by the unit cost (₹7/unit):

$$\text{Electricity} = \frac{\text{Monthly Bill}}{7} \times 12$$

Table 4.29 Public Building Electricity Consumption

Cluster	Monthly Bill Estimate	Electricity Use (kWh/year)
Kadoli	₹10,000	17,143
Tarsa	₹15,000	25,714
Kirmiti	₹10,000	17,143

D. Agricultural Pump Electricity Consumption

Pump count estimated from agricultural land assuming **1 pump per 12 ha** (Kadoli), **1 per 10 ha** (Tarsa), and **1 per 18 ha** (Kirmiti). Each pump consumes **3996 kWh/year** (5 HP, 6 hrs/day, 180 days).

$$\text{Total Electricity} = \text{No. of Pumps} \times 3996$$

Table 4.30 Agricultural Pump Electricity Consumption

Cluster	Pumps	Agriculture Electricity (kWh/year)
Kadoli	133	531,468
Tarsa	328	1,309,488
Kirmiti	71	283,716

E. Industrial Electricity Consumption

Based on average electricity usage per unit:

- Small-scale (Kadoli): 3000 kWh/year
- Medium/Agro (Kirmiti): 9000 kWh/year
- Large-scale (Tarsa): 50,000–700,000 kWh/year

Table 4.31 Industrial Electricity Consumption

Cluster	Industries	Electricity Use (kWh/year)
Kadoli	120 × 3000	360,000
Tarsa	5×50,000 + 1×700,000	950,000
Kirmiti	100 × 9000	900,000

Table 4.32 Cluster-Wise Total Electricity Use

Cluster	Household (kWh)	Streetlight (kWh)	Public (kWh)	Agriculture (kWh)	Industry (kWh)	Total (kWh)
Kadoli	2,340,000	30,310	17,143	531,468	360,000	3,278,921
Tarsa	2,964,600	91,980	25,714	1,309,488	950,000	5,341,782
Kirmiti	3,661,200	133,152	17,143	283,716	900,000	4,995,211

Scope 2 Emissions Calculation

Using the Scope 2 formula:

$$\text{Scope 2 Emissions (tons } CO_2) = \frac{\text{Electricity (kWh)} \times 0.82}{1000}$$

Table 4.33 Scope 2 Emissions Calculation

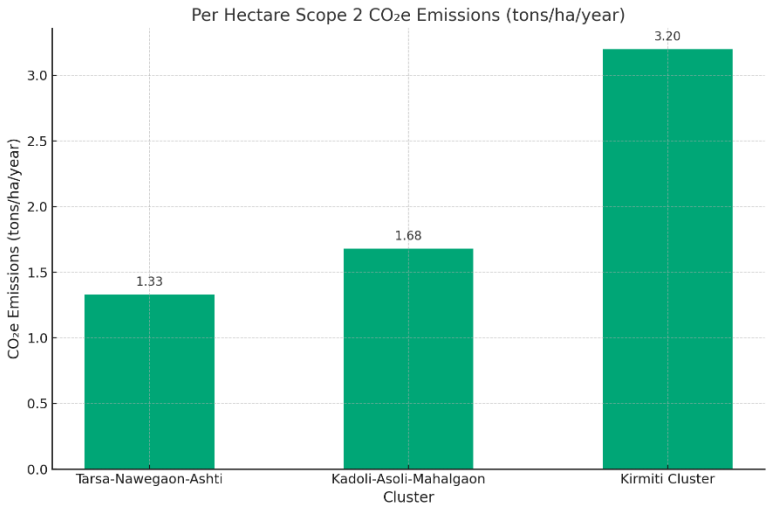
Cluster	Total Electricity (kWh)	Scope 2 Emissions (tCO_2/year)
Kadoli	3,278,921	**2,688.72**
Tarsa	5,341,782	**4,380.26**
Kirmiti	4,995,211	**4,096.07**

Per Capita and Per Hectare Scope 2 Emissions

$$\text{Per Capita} = \frac{\text{Total Scope 2 Emissions}}{\text{Population}}, \quad \text{Per Hectare} = \frac{\text{Total Scope 2 Emissions}}{\text{Land Area (ha)}}$$

Table 4.34 Per Capita and Per Hectare Scope 2 Emissions

Cluster	Population	Area (ha)	Per Capita (tCO_2/person)	Per Hectare (tCO_2/ha)
Kadoli	6483	1600	**0.415**	**1.68**
Tarsa	7215	3284	**0.607**	**1.33**
Kirmiti	5881	1279	**0.696**	**3.20**



- **Kirmiti Cluster** has the **highest per capita (0.696)** and **per hectare (3.20)** Scope 2 emissions, attributed to dense industrial use on a compact land base.

Figure 4.4 Clusterwise Scope 2 Emissions

- **Tarsa Cluster** has **moderate per capita emissions** and the **lowest per hectare intensity** due to its expansive agricultural landscape, which spreads electricity usage.
- **Kadoli Cluster** reflects **balanced electricity use** across all sectors, resulting in **lowest per capita emissions (0.415)** and moderate land intensity.

Chapter -5

PROPOSED DECARBONISATION STRATEGIES AND PLANNING INTERVENTIONS

5.1 Proposal for Agrarian Cluster

Mauda Growth Centre: Planned vs. Actual Development

The Mauda Growth Centre exhibits a notable divergence between its original land use planning and current ground realities. Agricultural land use continues to dominate the region, occupying approximately 81.38% of the total area, which is significantly higher than the 62.9% allocated for agriculture in the original plan. This discrepancy underscores that Mauda remains fundamentally agrarian in character, which provides a favorable context for implementing sustainable agricultural innovations such as agrivoltaics, low external input sustainable agriculture (LEISA), and watershed-based farming systems (TERI, 2022).

Table 5.1 Mauda growth center: planned development and actual development

Land Use	Planned (%)	Developed (%)	Key Observations
Residential	8.82%	3.93%	Underdeveloped; possibly due to NTPC land acquisition & low in-migration
Industrial	10.32%	3.62%	Industrial growth much below expectation; suggests room for decentralized clean industries or agro-processing units
NTPC (Power)	0%	10.75%	Major land was diverted to NTPC after the plan; unaccounted in RP 2011
PSP	0.27%	0.32%	Marginal increase; insignificant overall impact
Agriculture	62.9%	81.38%	Huge dominance of agriculture; exceeds allocation by ~18%
Horticulture	**17.68%**	**0%**	Entirely undeveloped; this is a **major opportunity gap**

S. No	Land Use	% of Total Area (RP 2011)	Area (sq.km)	Area (ha)
1	Residential	8.82%	32.51	3,251
2	Industrial	10.32%	38.04	3,804
3	NTPC	0.00%	0.00	0
4	PSP	0.27%	0.99	99
5	Agriculture	62.9%	231.78	23,178
6	Horticulture	**17.68%**	**65.19**	**6,519**
Total		**100%**	**368.6**	**36,860**

Table 5.2 Land use of Mauda and its Area Distribution

One of the most significant implementation gaps is the complete neglect of planned horticultural zones. While 17.68% of land was designated for horticulture in the master plan, none of this area has been developed for the intended purpose. This oversight presents a strategic opportunity to reintroduce horticultural practices within an agrivoltaic framework, especially under solar panel installations. Crops such as turmeric, lemongrass, and onions are well-suited for cultivation in shaded environments and could thrive under solar arrays, enabling dual land use and enhanced productivity (MNRE, 2022).

Industrial development in Mauda has also lagged the planned vision. Only 3.62% of the area has been developed for industrial use, as compared to 10.32% originally earmarked. This indicates potential for decentralizing eco-sensitive industrial activities such as agro-processing and localized solar module manufacturing, aligning industrial growth with environmental sustainability goals (NITI Aayog, 2023).

An additional disruption to the planned development arose from the acquisition of approximately 10.75% of the land by the National Thermal Power Corporation (NTPC), which was not accounted for in the original regional plan. This unplanned occupation highlights the need to revise land-use strategies to accommodate changing energy infrastructure dynamics. One promising approach could be to integrate agrivoltaic solar farms around the thermal plant to facilitate a just energy transition and enhance land use efficiency.

Looking forward, land use dynamics suggest that agricultural land will decrease from 81.38% to the originally planned 62.9%, resulting in a land shift of approximately 7,000 hectares. Simultaneously, the horticulture sector is expected to expand from 0% to 17.68%, offering a prime opportunity to promote horti-voltaic agriculture. As residential and industrial zones expand, it will become increasingly important to implement green buffer zones to mitigate ecological impacts and support sustainable urban-rural interfaces (World Resources Institute (WRI) & World Business Council for Sustainable Development (WBCSD), 2004).

5.1.1 Decarbonizing Paddy Fields through Agrivoltaic Integration: A Scientific Approach:

Agricultural rice cultivation is one of the largest contributors to greenhouse gas (GHG) emissions in rural India, predominantly due to methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O) emissions. The integration of agrivoltaic systems—where photovoltaic (PV) panels are installed above cropland—offers a scientifically robust and multifunctional solution to decarbonise paddy agriculture. This section presents an evidence-based approach to mitigating emissions through agrivoltaics by addressing energy use, water management, and nutrient application.

1. Methane Emissions from Flooded Rice Fields

Flooded rice fields create anaerobic soil conditions that promote methanogenesis, releasing large amounts of CH_4 into the atmosphere (IPCC, 2014). Continuous flooding also leads to inefficient water use and groundwater depletion.

Agrivoltaic systems provide decentralized solar-powered irrigation, facilitating the adoption of Alternate Wetting and Drying (AWD)—an irrigation method where fields are intermittently dried to suppress methane production. According to the International Rice Research Institute (IRRI, 2019), AWD reduces methane emissions by up to 70% compared to continuously flooded fields. The FAO (2021) similarly highlights that solar-based AWD enhances both water use efficiency and CH_4 mitigation.

Recent findings published in Nature Communications (2024) further confirm that solar-powered irrigation systems improve micro-irrigation control, enabling farmers to time irrigation precisely and transition away from flood-based practices. These benefits collectively reduce CH_4 emissions while maintaining or increasing rice yields.

2. Carbon Dioxide Emissions from Diesel-Powered Irrigation Problem:

In many rural areas, irrigation remains dependent on diesel generators or fossil-fuel-intensive grid electricity. A single 1 HP diesel pump, when operated under average conditions, emits approximately 3.8 tonnes of CO_2 per year (ICAR, 2020), making it a significant carbon hotspot in paddy farming.

Agrivoltaic panels installed on agricultural land can replace diesel use entirely by supplying clean, renewable electricity. According to a joint report by NITI Aayog and MNRE (2022), replacing diesel pumps with solar under the PM-KUSUM scheme has the potential to reduce 30 million

tonnes of CO_2 annually at the national level. In addition, studies from the National Renewable Energy Laboratory (NREL, 2020) show that agrivoltaic installations can generate between 0.5–1 MW per hectare, adequately powering water pumps for irrigation while achieving net-zero operational emissions. This makes agrivoltaics not just a clean energy substitution but also a pathway for energy sovereignty in agriculture.

3. Nitrous Oxide Emissions from Fertilizer Use Problem:

N_2O emissions arise from the overuse or misapplication of nitrogen fertilizers, especially in water-saturated soils with high Water-Filled Pore Space (WFPS). These conditions are prevalent in traditional paddy cultivation, which often lacks precision in nutrient management (FAO, 2019; IPCC, 2014).

Agrivoltaics improve soil microclimate by reducing evaporation and moderating temperature through shading. This helps maintain optimal soil moisture conditions that discourage denitrification and N_2O formation. Moreover, the integration of precision fertigation (fertilizer application via irrigation) systems, powered by solar energy, supports the implementation of 4R Nutrient Stewardship (Right source, Right rate, Right time, Right place). A study by Ferland et al. (2024) published in Science of the Total Environment demonstrated that the use of improved nitrogen management techniques—including reduced rates and efficiency-enhancing formulations—led to a 57% reduction in N_2O emissions over three years, with no yield losses. The reduction was most prominent in plots with WFPS greater than 50%, a condition that agrivoltaics can help mitigate through controlled irrigation and shading.

A multi-criteria geospatial assessment was carried out to identify optimal sites for agrivoltaic deployment in the Tarsa–Nawegaon–Ashti agrarian cluster. The analysis considered solar radiation, land use, slope, aspect, accessibility, vegetation cover (NDVI), land surface temperature (LST), and global horizontal irradiance (GHI) to ensure suitability for dual-use of land—solar energy generation and agriculture.

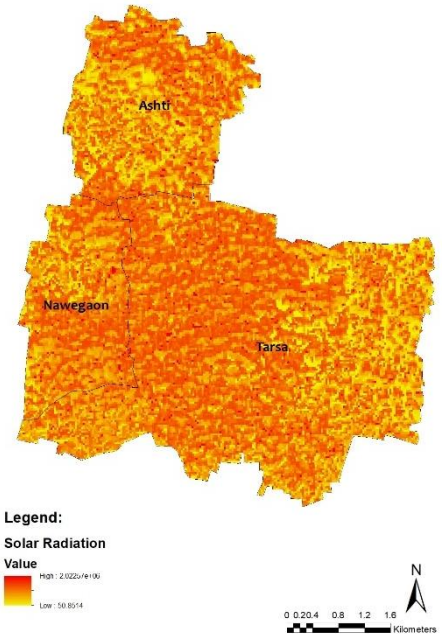


Figure 5.1 Solar Radiation Map

1. Solar Radiation

The region exhibits high solar radiation potential, ranging between 1.8–2.0 × 10^6 Wh/m² annually, as shown by the deep orange-to-red shades on the solar radiation map. This intensity makes the entire cluster highly suitable for solar photovoltaic (PV) applications, which is a fundamental precondition for agrivoltaics.

Implication: High insolation ensures reliable solar power generation to support irrigation and farm electrification.

Recommendation: Prioritize these high-radiation zones for ground-mounted solar PV installation, especially in areas where land can be dual-purposed without productivity loss.

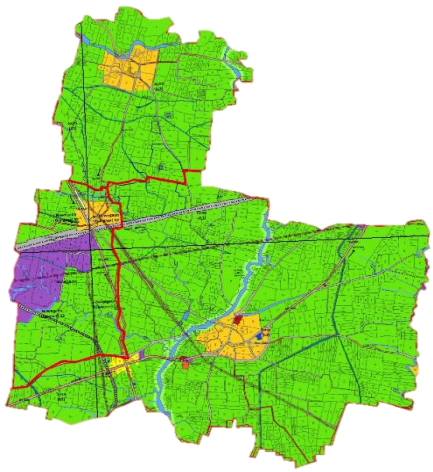


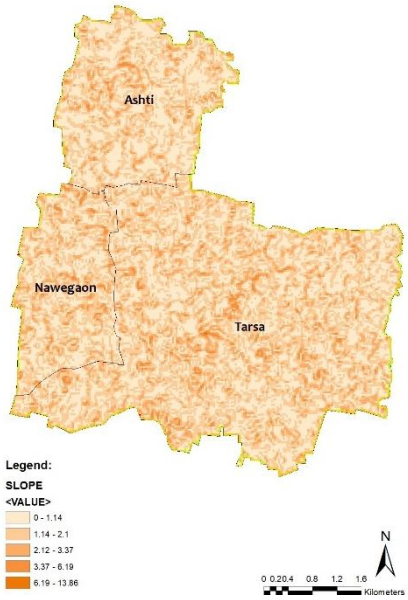
Figure 5.2 Landuse Map

2. Land Use

Most of the land in the cluster is classified as irrigated agricultural land (A1 category), marked in green on the land use map. This type supports year-round cropping and offers favorable terrain for solar deployment.

Implication: A1 lands are ideal for agrivoltaic integration as they are actively cultivated and benefit from sustainable energy interventions.

Recommendation: Select A1 zones, especially near road networks, for initial agrivoltaic trials—preferably near the industrial fringe of Nawegaon for pilot-scale demonstration.

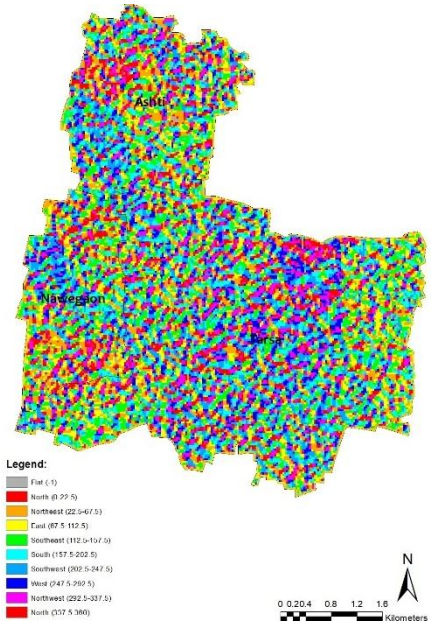


3. Slope

The terrain is predominantly gentle, with slopes ranging between 0–3.37°. A few patches exhibit slopes up to 13°, which are less favorable for solar infrastructure due to stability issues.

Implication: Gentle slopes (<3.5°) support easier installation and accessibility for solar PV mounting structures, enabling cost-effective deployment. Recommendation: Target zones with <3.5° slope for Phase 1 deployment to minimize the need for elevated mounting and excavation.

Figure 5.3 Slope Map

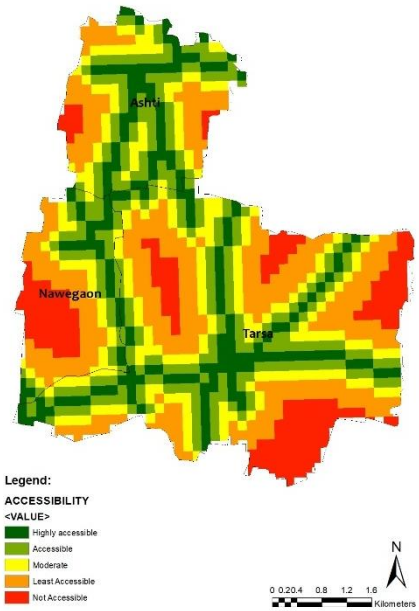


4. Aspect

The aspect map shows a diverse distribution of land orientations with no single dominant direction. However, many areas are south, southwest, or southeast-facing—known for optimal solar capture throughout the year.

Implication: South-facing slopes offer higher solar energy yield due to better sun exposure. Recommendation: Prioritize areas facing south, southwest, and southeast for panel installation, particularly on elevated bunds and plot boundaries.

Figure 5.4 Aspect Map



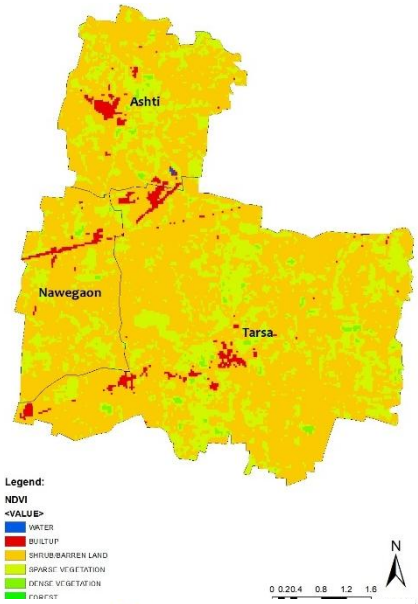
5. Accessibility

Accessibility analysis reveals that the central parts of the cluster are highly accessible (green zones), whereas peripheral regions are moderate to least accessible (yellow to red).

Implication: Accessibility determines ease of construction, maintenance, and transmission from solar installations.

Recommendation: Select green and yellow zones in the initial phase, particularly around Tarsa and Nawegaon, for lower logistical costs and better infrastructure support.

Figure 5.5 Accessibility Map

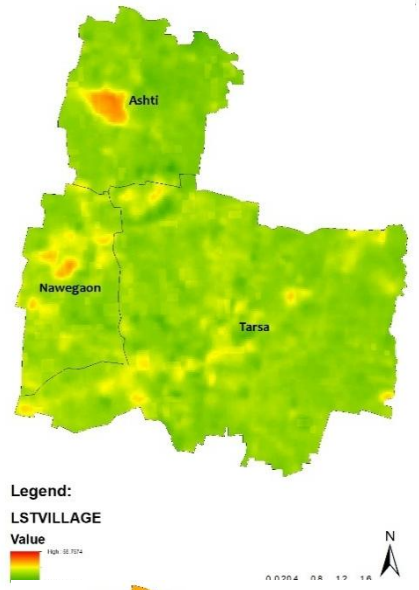


5. Vegetation Cover (NDVI)

The NDVI map indicates that the majority of the land comprises sparse vegetation (yellow–light green), with pockets of dense green and built-up areas. Implication: Sparse vegetated land is favorable for agrivoltaics as it allows dual land use without significant ecological disturbance.

Recommendation: Avoid densely vegetated areas and forests; prioritize yellow-light green zones for integration.

Figure 5.6 NDVI Map



6. Land Surface Temperature (LST)

LST values in the cluster range from 58–65°C in hotspot zones, particularly around Ashti and Nawegaon. These moderate temperatures are acceptable for PV efficiency and can even benefit from the shading provided by panels.

Implication: Agrivoltaics can reduce local LST through panel shading, helping to mitigate heat stress and create a microclimate suitable for certain crops.

Recommendation: Prioritize moderate LST zones to maximize the climate regulation benefits of agrivoltaic systems.

Figure 5.7 LST Map

7. Global Horizontal Irradiance (GHI)

The GHI map shows a uniform value of 5.2 kWh/m²/day across the cluster, indicating consistently high solar availability throughout the year.

Implication: This consistency ensures reliable power generation potential for off-grid rural solar irrigation systems and agrivoltaic units.

Recommendation: All three villages (Tarsa, Nawegaon, Ashti) are equally suitable based on GHI; prioritize based on land use, slope, and access.

Figure 5.8 Global Horizontal Irradiance

Final Land Suitability Analysis for Agrivoltaics

The composite land suitability map revealed that large portions of Tarsa and Ashti demonstrate "suitable" to "highly suitable" potential for agrivoltaic deployment. These zones are represented as light to dark green areas in the integrated map layers, indicating optimal combinations of flat terrain, high solar exposure, irrigated agricultural land, and good accessibility. On the other hand, Nawegaon showed a more fragmented suitability pattern, with moderate suitability (yellow zones) and some least suitable areas (orange to red) concentrated in the western and southwestern parts of the village.

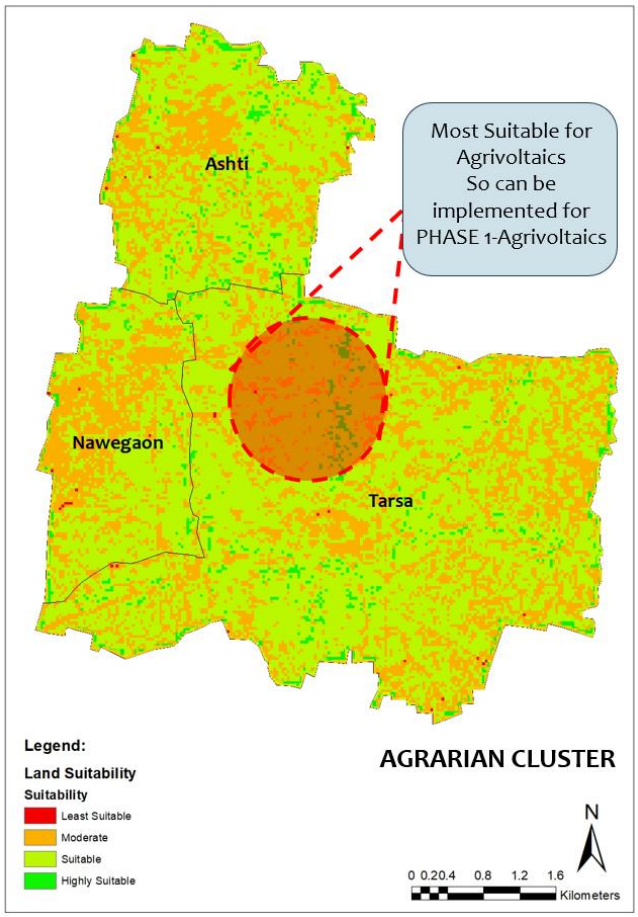


Figure 5.9 Land Suitability Map of Agrarian Cluster for Agrivoltaics

Interpretation of Suitability Zones
Highly Suitable Zones (green):

These areas are prioritized for Phase 1 agrivoltaic deployment.

They include:

- Southern Ashti
- Central Tarsa
- East-central Nawegaon.

These locations likely scored high on most suitability layers, including:

- Strong solar radiation
- Flat terrain (gentle slope <3.5°)
- Easy access (near roads or central zones)
- Active agricultural use (A1 land)

Table 5.3 Village Wise Suitability Insights

Village	Highly Suitable Zones	Notes
Tarsa	Spread across central and eastern zones	Good accessibility, irrigated land, and moderate land surface temperature
Nawegaon	Limited, mostly in eastern and central patches	Western zones have low NDVI and poor access
Ashti	Dense patches in northern and southern agricultural belts	High suitability due to strong solar radiation, road network, and sparse built-up

5.1.1.1 Agrivoltaic Performance Assessment: Agrivoltaic Performance Assessment: Energy Generation, Emission Mitigation, and Revenue Analysis

This section presents a detailed performance and impact analysis of a moderate-density agrivoltaic system applied to a 1-hectare rice-wheat plot, combining solar electricity generation with sustainable farming. The parameters are derived from real-world data and studies in Maharashtra (e.g., Dhule, Parbhani) and adapted to the solar and agricultural context of the Tarsa–Nawegaon–Ashti cluster.

1. Solar Capacity Installed

The assumed system uses a **moderate-density configuration of 250 kW per hectare**, a balance that enables efficient solar capture while maintaining space for crops to grow underneath. This estimate aligns with actual installations observed in **Parbati** and **Dhule**, where densities typically range between 200–400 kW/ha under flat-mounted or elevated designs suitable for mechanized farming.

2. Annual Energy Generation

Using the **solar irradiance of Nagpur (~5.1 kWh/m²/day)** and assuming a **specific yield** of **1500–1700 kWh per kW per year**, the total **annual energy output** is estimated using:

$$\text{Energy Output (kWh)} = \text{Installed Capacity (kW)} \times \text{Specific Yield (kWh/kW/year)}$$
$$= 250 \times (1500 \text{ to } 1700) = 375,000 \text{ to } 425,000 \text{ kWh/year}$$

This equates to approximately **0.4 GWh/year per hectare**.

3. CO_2 Emissions Avoided

The system offsets emissions by replacing conventional grid electricity (coal-dominated). Using India's average **grid emission factor** of **0.716 tCO_2/MWh** (CEA, 2022):

$$CO_2 \text{ Saved (tons)} = \text{Energy Output (MWh)} \times 0.716 = 400 \times 0.716 = \mathbf{286.4 \text{ tonnes } CO_2/\text{year}}$$

4. Crop Yield under Agrivoltaics (Rice + Wheat)

Baseline yields for paddy and wheat under conventional farming are:

Rice: 2.5 t/ha (Kharif)

Wheat: 2.0 t/ha (Rabi)

Total baseline = 4.5 t/ha

Under agrivoltaic shading, studies indicate **15–30% yield reduction**, but optimization allows recovery up to 80% of the baseline:

$$\text{Adjusted Yield} \approx 3.6 \text{ tonnes/ha/year}$$

5. Crop Revenue

Using conservative **farm-gate prices**:

Rice: ₹18/kg × 2 t = ₹36,000

Wheat: ₹20/kg × 1.6 t = ₹32,000

$$\text{Total Crop Revenue} = ₹68,000–₹70,000/ha/year$$

6. Solar Revenue

Using average generation of **400,000 kWh/year** and PM-KUSUM / MSEDCL **feed-in tariff** of ₹3.1/kWh:

$$\text{Solar Revenue} = 400,000 \times 3.1 = ₹12.4 \text{ lakh/year}$$

Estimated range: **₹12–13 lakh/year per hectare**

7. Total Revenue Comparison

Total revenue from agrivoltaics (crop + energy):

$$\text{Total Revenue} = ₹70,000 + ₹12.4 \text{ lakh} \approx \mathbf{₹13.1 \text{ lakh/ha/year}}$$

Compared to conventional **crop-only revenue** of **₹85,000/ha**, agrivoltaics yields **15×highertotal revenue**, even after accounting for yield loss.

Table 5.4 Agrivoltaic Performance Table

Parameter	Value
Solar Capacity Installed	250 kW/ha (moderate density)
Annual Energy Generation	375,000–425,000 kWh/year (~0.4 GWh)
CO_2 Emissions Avoided	270–300 tonnes/year
Crop Yield (Rice + Wheat)	~3.6 tonnes/year (~80% of baseline)
Crop Revenue	₹70,000/ha
Solar Revenue	₹12–13 lakh/ha/year
Total Revenue	**₹13.1 lakh/ha/year**

5.1.2 Decarbonising Paddy Fields through Alternate Wetting and Drying Technique

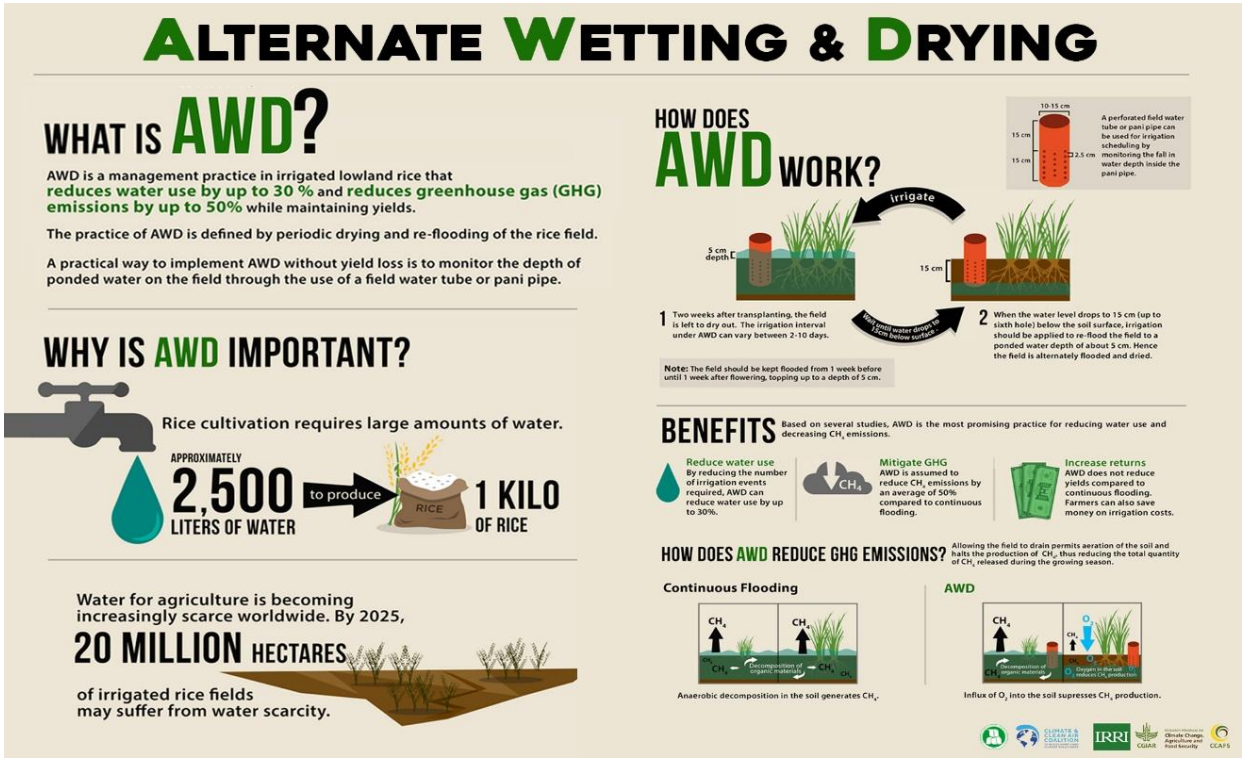

ALTERNATE WETTING & DRYING
WHAT IS AWD?
AWD is a management practice in irrigated lowland rice that reduces water use by up to 30 % and reduces greenhouse gas (GHG) emissions by up to 50% while maintaining yields.
The practice of AWD is defined by periodic drying and re-flooding of the rice field.
A practical way to implement AWD without yield loss is to monitor the depth of ponded water on the field through the use of a field water tube or pani pipe.
WHY IS AWD IMPORTANT?
Rice cultivation requires large amounts of water.
APPROXIMATELY 2,500 LITERS OF WATER to produce 1 KILO OF RICE
Water for agriculture is becoming increasingly scarce worldwide. By 2025,
20 MILLION HECTARES
of irrigated rice fields may suffer from water scarcity.
HOW DOES AWD WORK?
A perforated field water tube or pani pipe can be used for irrigation scheduling by monitoring the fall in water depth inside the pani pipe.
irrigate
1 Two weeks after transplanting, the field is left to dry out. The irrigation interval under AWD can vary between 2-10 days.
2 When the water level drops to 15 cm (up to sixth hole) below the soil surface, irrigation should be applied to re-flood the field to a ponded water depth of about 5 cm. Hence the field is alternately flooded and dried.
Note: The field should be kept flooded from 1 week before until 1 week after flowering, topping up to a depth of 5 cm.
BENEFITS Based on several studies, AWD is the most promising practice for reducing water use and decreasing CH4 emissions.
Reduce water use By reducing the number of irrigation events required, AWD can reduce water use by up to 30%.
Mitigate GHG AWD is assumed to reduce CH4 emissions by an average of 50% compared to continuous flooding.
Increase returns AWD does not reduce yields compared to continuous flooding. Farmers can also save money on irrigation costs.
HOW DOES AWD REDUCE GHG EMISSIONS? Allowing the field to drain permits aeration of the soil and halts the production of CH4, thus reducing the total quantity of CH4 released during the growing season.
Continuous Flooding
AWD
Anaerobic decomposition in the soil generates CH4.
Influx of O2 into the soil supresses CH4 production.

Figure 5.10 Alternate Wetting and Drying Technique

IPCC Tier 1 & AWD Methane Mitigation Framework

According to the *IPCC Guidelines for National Greenhouse Gas Inventories* (2006; 2019 refinement), rice methane (CH_4) emissions vary by water management regime. AWD, or Alternate Wetting and Drying, is classified as an *intermittent flooding* method which significantly reduces methane emissions compared to continuous flooding.

Table 5.5 Water Management Regime as per IPCC 2006, 2009 Refinement

Water Management Regime	Emission Factor (kg CH_4/ha/day)	Relative Emission Level
Continuously flooded	1.30–2.00	Highest
Intermittently flooded (AWD)	0.50–0.90	40–60% lower
Rainfed (no water control)	~0.20–0.30	Lowest

IPCC 2019 Refinement on AWD:

AWD oxidizes the topsoil and interrupts methanogenesis. It maintains yields if timed properly. It can be integrated with nitrogen management for co-benefits. Officially identified as a *Tier 2 mitigation practice* for national GHG inventory reporting under UNFCCC.

Table 5.6 AWD-Based Emission Reduction in Tarsa–Nawegaon–Ashti Cluster

Parameter	Value
Total Rice Area (Tarsa Cluster)	2,000 ha
CH_4 Emissions from Rice	2,600 tons CH_4/year
GWP of CH_4 (IPCC AR6)	1 ton CH_4 = 27.2 tons CO_2e
Total CO_2e Emissions from Rice (Scope 1)	70,720 tons CO_2e/year
Emission Reduction via AWD (50% average)	35,360 tons CO_2e/year

Table 5.7 Summary table for AWD-Based Emission Reduction in Tarsa–Nawegaon–Ashti Cluster

Cluster	Rice Area (ha)	CH_4 Emissions (t)	CO_2e Emissions (t/year)	AWD Reduction (50%)
Tarsa–Nawegaon–Ashti	2,000	2,600	70,720	35,360

In the irrigated rice fields of Tarsa–Nawegaon–Ashti, AWD can mitigate methane emissions by ~35,360 tons of CO_2e annually.

5.1.3 Functional Synergy of AWD + Agrivoltaics

Table 5.8 Functional Synergy of AWD + Agrivoltaics

Aspect	AWD	Agrivoltaics
Primary Goal	Reduce water use in paddy fields	Dual land use: solar + agriculture
Land Use	Paddy fields	Raised solar panels above fields
Water Management	Controlled irrigation required	Panels reduce evaporation by shading
Sunlight Needs	Intermittent sunlight tolerated	Panels absorb sunlight above; shade-tolerant crops below
Result	Less standing water	Better moisture retention, reduced heat stress
Combined Impact	Disrupts CH_4 generation	Enables AWD and supports yield resilience

1. Agrivoltaic Crop & Land Use Recommendations for Nagpur

Table 5.9 Agrivoltaic Crop & Land Use Recommendations for Agrarian Cluster in Nagpur

Climate: Tropical dry-wet zone

Main Crops: Kharif – Rice, Rabi – Wheat

Crop	Shading Impact	Design Suggestion
Rice	27–39% shading retains ~80% yield	20–30% panel coverage; elevated or spaced rows
Wheat	13% shading negligible; 41% = ~30% loss	Minimal shade or winter-season panels
Fruit Crops	(Guava, Citrus, Moringa) – suitable	Hortivoltaics with 3–4m high panels and row gaps

2. Environmental & Carbon Benefits Table of Agrivoltaics and AWD

Table 5.10 Environmental & Carbon Benefits Table of Agrivoltaics and AWD

Impact Area	AWD	Agrivoltaics	Combined Benefit
Methane Emission	↓ by 30–70%	Neutral	AWD breaks anaerobic conditions
Water Use	↓ by 15–30%	↓ indirectly	Reduced evapotranspiration + AWD-controlled irrigation
Land Productivity	Maintained or increased	Dual output	Energy + food yield from same area
Carbon Emissions	↓ CH_4	↓ CO_2 via green power	Effective Scope 1 and 2 reduction model

Table 5.11 Proposed Interventions and Carbon Sequestration Potential for Agrarian Based Cluster

Proposal / Intervention	Estimated CO_2 Sequestered (tons/year)	Basis / Area / Units Considered	Key Assumption / Source
Agrivoltaics (Scope 2 Offset)	4,380	5.34 GWh/year agri electricity demand (~3.3 MW capacity)	Replaces grid electricity; emission factor = 0.82 kg CO_2/kWh (CEA); PM-KUSUM solar capacity
AWD on Paddy Fields	20,000	2,000 ha rice fields × 35% CH_4 reduction	IPCC Tier 1; CH_4 GWP = 27.2; based on ICAR and InfoCrop verified field results

Proposal / Intervention	Estimated CO_2 Sequestered (tons/year)	Basis / Area / Units Considered	Key Assumption / Source
Biochar Application	3,900	2,600 ha × 1.5 tCO_2/ha/year	Crop waste to pyrolysis conversion; IPCC Tier 1, FAO/ICAR reference for soil application
Compost / Vermicompost Units	780	60% adoption on 2,600 ha × 0.5 tCO_2/ha	Soil carbon buildup + fertilizer substitution; FAO + MoAFW sources
TOTAL ESTIMATED SEQUESTRATION	~29,060 tCO_2/year	—	All estimates avoid overlaps and double-counting for high integrity

Through the implementation of practical and scientifically validated interventions—such as agrivoltaics, alternate wetting and drying (AWD), composting, and biochar—the Tarsa agrarian cluster demonstrates the potential to sequester approximately 29,060 tons of CO_2 annually.

This sequestration strategy offsets 100% of Scope 2 emissions (primarily from agricultural electricity consumption) and approximately 37% of Scope 1 emissions, including those from methane emissions in rice fields and diesel usage. These results suggest that village-level decarbonisation is not only technically feasible but also scalable using cost-effective, field-tested practices tailored to local land use and energy patterns.

Thematic Layer	Strategy	Justification	Phase	Scope Targeted
Spatial Planning	**Agrivoltaics on Paddy Fields**	Double-cropped paddy emits CH_4 and needs irrigation. Overhead solar panels (AV) allow dual land use. Income from crop + solar. Fits **PM-KUSUM A**. NDVI + irrigation data to guide site selection.	Phase 1–2	Scope 1 (CH_4), Scope 2
	Agroforestry on Bunds/Rangelands	Neem, pongamia, bamboo on bunds/rangelands improve soil & sequester CO_2. Doesn't affect crops. Uses **MNREGA labor + free saplings**.	Phase 1	Carbon Sink, Scope 3
Financial Structuring	**Carbon Credit Training for SHGs/Farmers**	Trains locals on monetizing low-carbon practices (AV, compost).	Phase 3	Scope 1
	Convergence of Schemes	Use **MNREGA** (bunds), **PM-KUSUM** (pumps), **NABARD SHG funds** (biogas/compost)	Phase 1–3	Scope 1, 2
Technological Tools	**AWD with Solar Pumps**	AWD cuts CH_4 up to 70%. Solar pumps automate cycles. Easy demo via KVK. Manual or IoT-based. Saves water + emissions.	Phase 1	Scope 1
	Crop Emissions Logbook + NDVI Tracking	Panchayat-maintained logbook of water, fertilizer, yield. Basic NDVI maps from Bhuvan. Aids GPDP planning + future carbon funding.	Phase 2	Scope 1, Governance
Livelihood & Inclusion	**SHG-led Compost + Biogas Units**	SHGs use dung/residue to create compost/gas. Sales under FCO norms. Supported by **NABARD, Swachh Bharat**, and **Ujjwala savings**.	Phase 2	Scope 1, Circular Economy
Urban–Rural Linkage	**Compost to City Parks/Organic Buyers**	SHGs sell village compost to cities for parks or organic retail. Boosts income and visibility. Enabled by **eNAM, City Compost Policy**.	Phase 2–3	Scope 3 + Economic Linkage
	EV Produce Transport (Pilot)	Introduce e-rickshaws/solar carts within 10 km for produce/compost. Youth-run. Schemes: **PM-eBus Seva**, **MoRTH EV fund**, CSR.	Phase 3	Scope 3
Policy Recommendation	**Gram Sabha Fertilizer Cap**	Local rule limiting urea overuse. Promote INM + soil health card use. Backed by **MoAFW toolkit**.	Phase 1	Scope 1 (N_2O), Regulation
	Mandatory Compost Use on Govt Plots	Require Panchayat/farm plots to use SHG-made compost. Replaces part of DAP/urea. Fits **NMSA** circular goals.	Phase 2	Scope 1 + Local Circularity

5.2 Proposal for Mixed Cluster

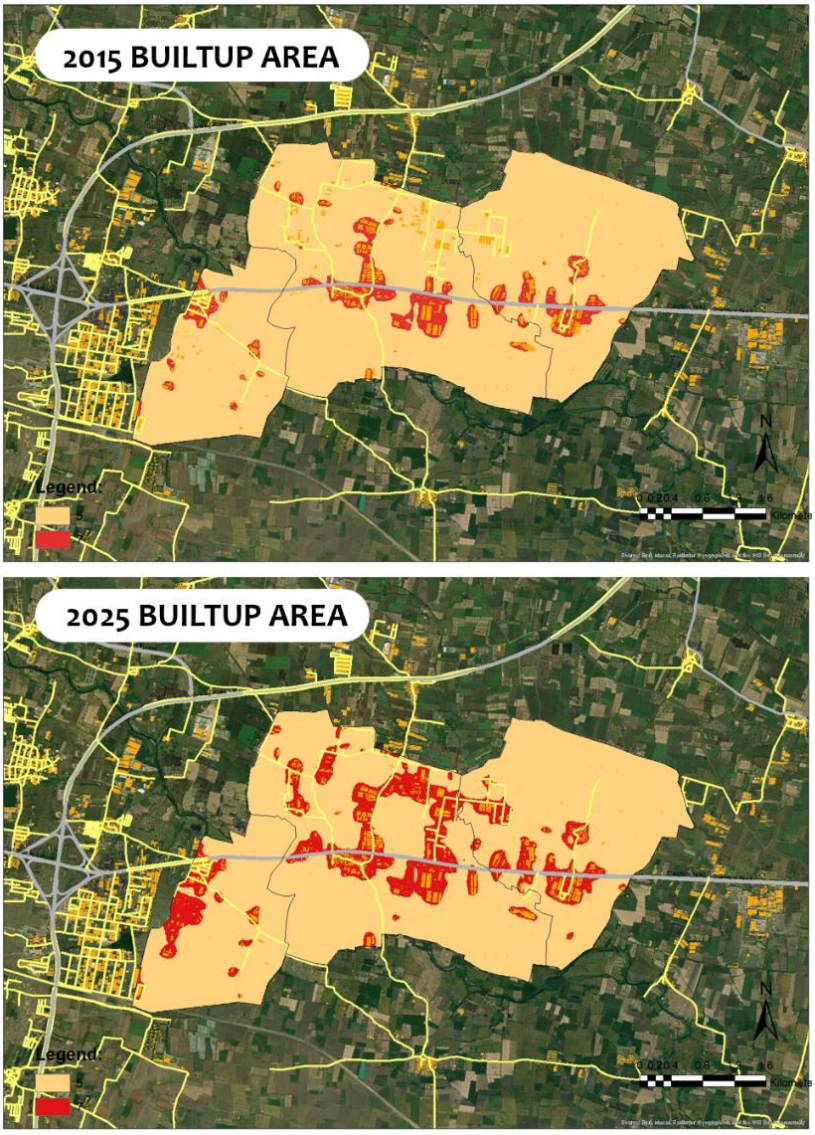


Figure 5.11 comparison of landuse built up area 2015 and 2025

. Between 2015 and 2025, the spatial growth pattern of the settlement has evolved significantly, transitioning from a relatively linear and compact development along major roads to a more scattered and fragmented built-up form. This transformation is particularly evident in the southern and northwestern directions, where new construction has extended beyond the original village boundaries. The shift indicates a lack of structured planning and suggests that growth is occurring in an unregulated manner. Such outward sprawl exerts pressure on valuable agricultural land and threatens the ecological balance of peripheral areas. The dispersion of built-up zones away from the village core can lead to the conversion of fertile farmland into non-agricultural uses, reducing the sustainability of local livelihoods dependent on farming. Furthermore, the 2025 land use pattern reveals the emergence of isolated pockets of development located far from the central village cluster. This peripheral fragmentation not only disrupts the continuity of the rural fabric but also poses practical challenges for infrastructure provisioning and public service delivery. Services such as roads, water supply, sanitation, and waste management become more difficult and expensive to extend to these disconnected areas. This kind of spatial disintegration weakens the overall efficiency of rural planning and may increase long-term environmental and fiscal costs. These trends highlight the urgent need for the implementation of proactive land use controls, such as delineation of growth boundaries, zoning regulations, and conservation of productive agricultural zones, to prevent haphazard expansion and to guide future development in a sustainable and inclusive manner.

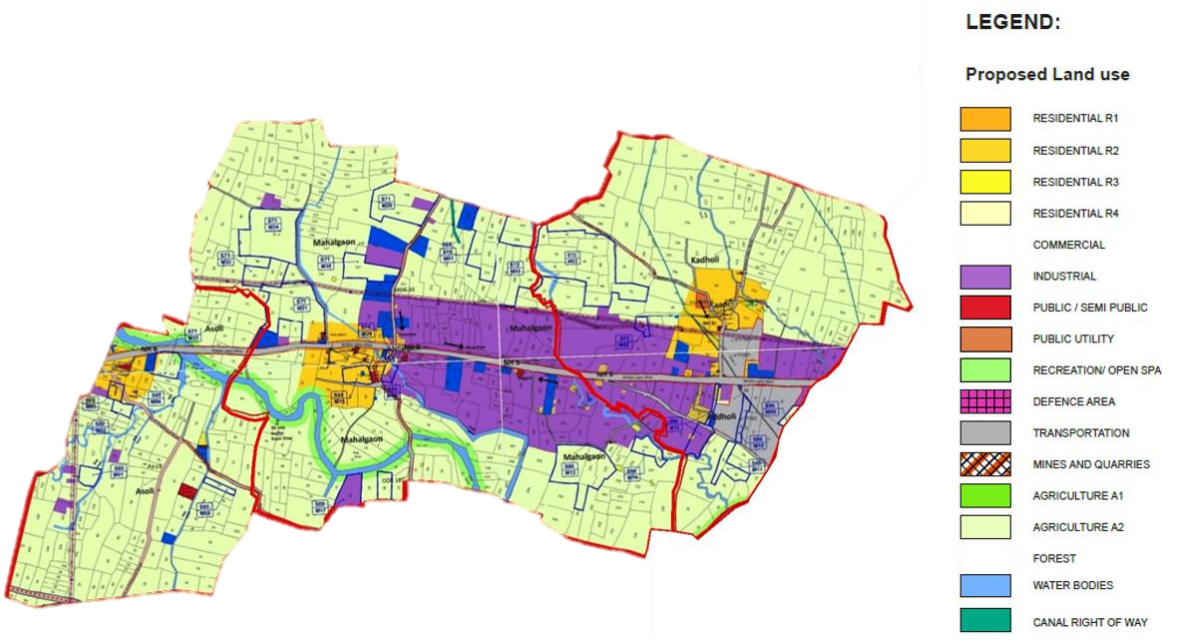


Figure 5.12 proposed land use

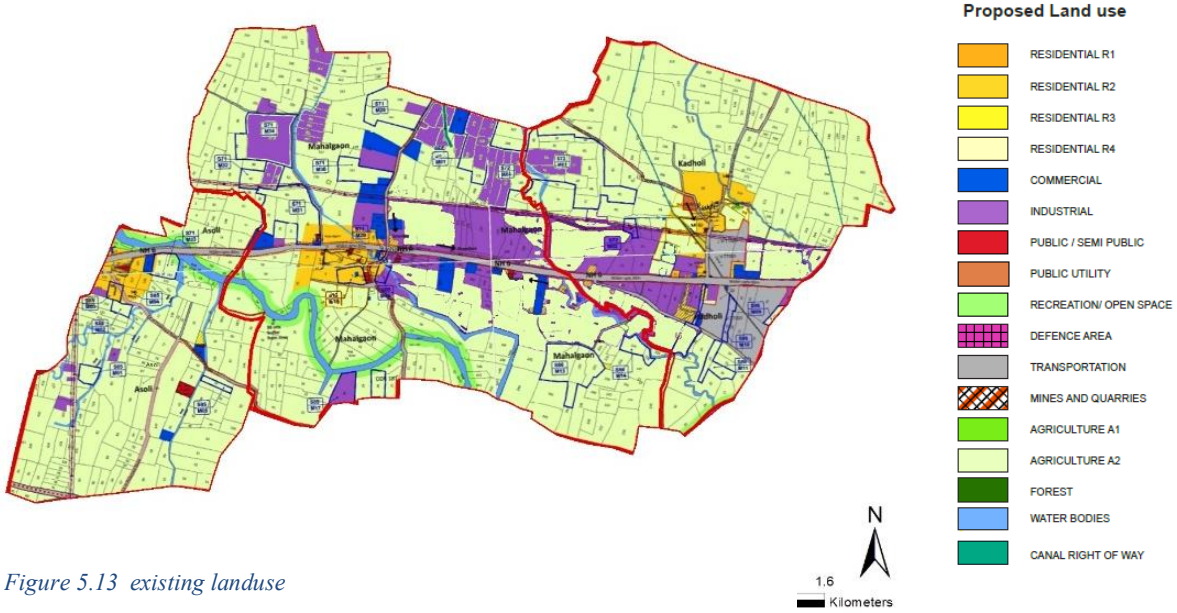


Figure 5.13 existing landuse

Observations:

The spatial development pattern reveals a significant mismatch between existing industrial activities and the planned industrial zones. Industries have encroached onto agricultural land, particularly high-quality irrigated (A1) farmland, along the main corridor, while the proposed industrial belt situated on the opposite side of the corridor remains largely vacant and underutilized. This misalignment stems primarily from inadequate transportation infrastructure, including missing last-mile connectivity, absence of dedicated service roads, and lack of freight movement support. As a result, industrial units have emerged in unregulated pockets where access

is convenient, rather than in designated zones, leading to inefficient land use, environmental stress, and loss of productive agricultural areas.

In addition, a noticeable trend in the proposed land use is the conversion of Agriculture A2 land—typically secondary yet still viable farmland—into industrial and residential uses. Much of this conversion is concentrated along the main transport corridor, where informal industrial development already exists on one side, while the other side has been earmarked for formal industrial expansion. This unbalanced and uncoordinated development reflects a reactive rather than proactive planning approach, further accelerating the loss of agricultural land and creating land use conflicts between residential, industrial, and farming functions.

Another critical concern is the absence of sufficient public and semi-public utility zones in both existing and proposed development patterns. The current built-up areas lack dedicated spaces for essential public services such as schools, healthcare centers, and recreational amenities. Moreover, the proposed land use plan underallocates public spaces within actual residential clusters, especially in newly emerging peripheral zones. This shortfall compromises equitable access to basic infrastructure and public services, particularly for residents in rapidly urbanizing fringes. Without timely intervention, this could exacerbate social disparities and reduce the overall quality of life in these transitioning rural–urban landscapes. (Refer Fig No 5.12 & 5.13)

5.2.1 Proposed Land Use and Connectivity Plan with Green Buffer Strategy for Carbon Sequestration in Kadoli–Asoli–Mahalgaon Cluster

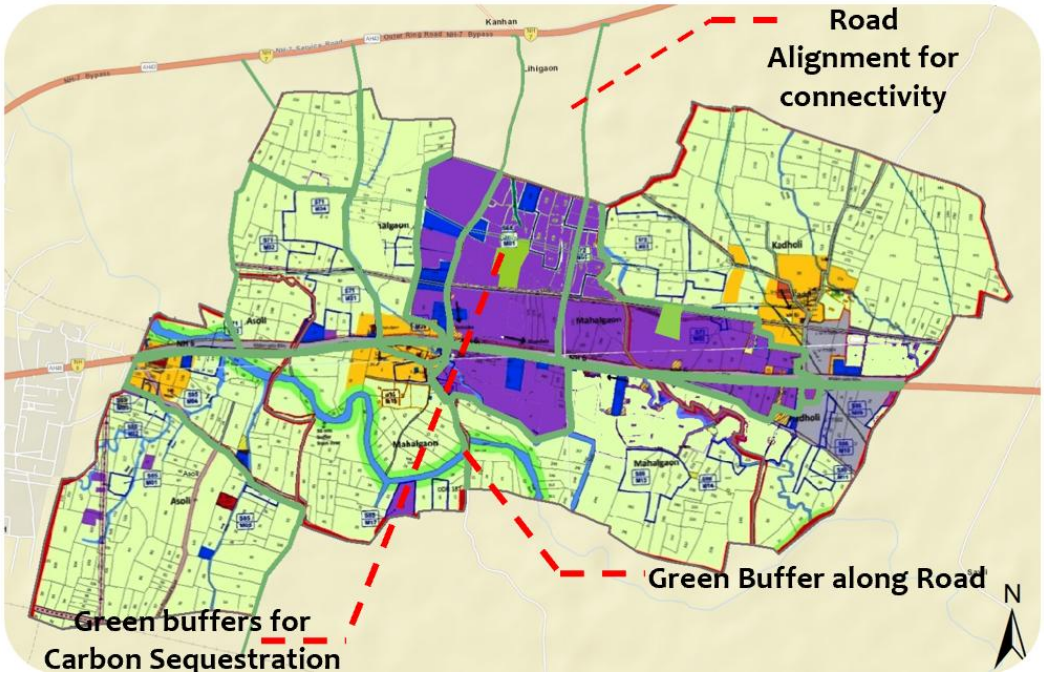


Figure 5.14 Proposed Land Use and Connectivity Plan with Green Buffer Strategy for Carbon Sequestration

Land Use Realignment Based on Actual Development:

Several agricultural zones within the cluster are already experiencing industrial development. These zones are being converted to industrial use to accommodate ongoing trends. Conversely, underutilized industrial lands are reassigned to agriculture or conservation to protect land resources and prevent unnecessary land conversion.

Infrastructure-Driven Enforcement:

Earlier planned industrial zones remained underdeveloped due to poor road connectivity. To address this, new road alignments have been proposed to activate these areas, particularly where emerging industrial activity has been observed. This strategy ensures planned industrial growth is supported by infrastructure.

Green Buffers for Emission Control:

Green buffer zones composed of fast-growing native species like Neem, Pongamia, and Bamboo are introduced around industrial zones. These act as pollution shields, reducing dust, noise, and air pollution while also enhancing microclimatic conditions. These buffers serve as natural carbon sinks and improve the overall environmental quality.

Table 5.13 Strategic Advantages of the Proposal

Emission Source	Scope Type	Strategic Advantages of the Proposal
Industrial activities (fuel combustion, process heat)	Scope 1	Concentrating industries where activity already exists avoids new land conversion emissions. Densification minimizes infrastructure-related emissions.
Electricity use in industries	Scope 2	Cluster-based development supports grid or renewable energy integration, thereby lowering reliance on fossil fuels.
Dust, noise, and air pollution near settlements	Scope 3 (indirect)	Green buffer zones mitigate pollution, sequester CO_2, and offer ecosystem services that offset emissions.
Road transport for goods/workers	Scope 3	Road realignment based on current industrial growth minimizes travel distance and congestion, thereby reducing emissions from transport activities.

Table 5.14 Guidelines for Green Buffer Development

Guideline	Focus Area	Suggested Width	Vegetation Type	Key Purpose
IPCC (2006, AFOLU)	Carbon Sequestration	As per land availability	Bamboo, Neem, Pongamia, and other fast-growing native species	Offset CO_2 emissions and improve green biomass cover
URDPFI (2015)	Spatial Planning & Zoning	30–50 m (Orange Category), 100–250 m (Red Category)	Native, pollution-tolerant trees	Buffer between industrial, agricultural, and residential areas

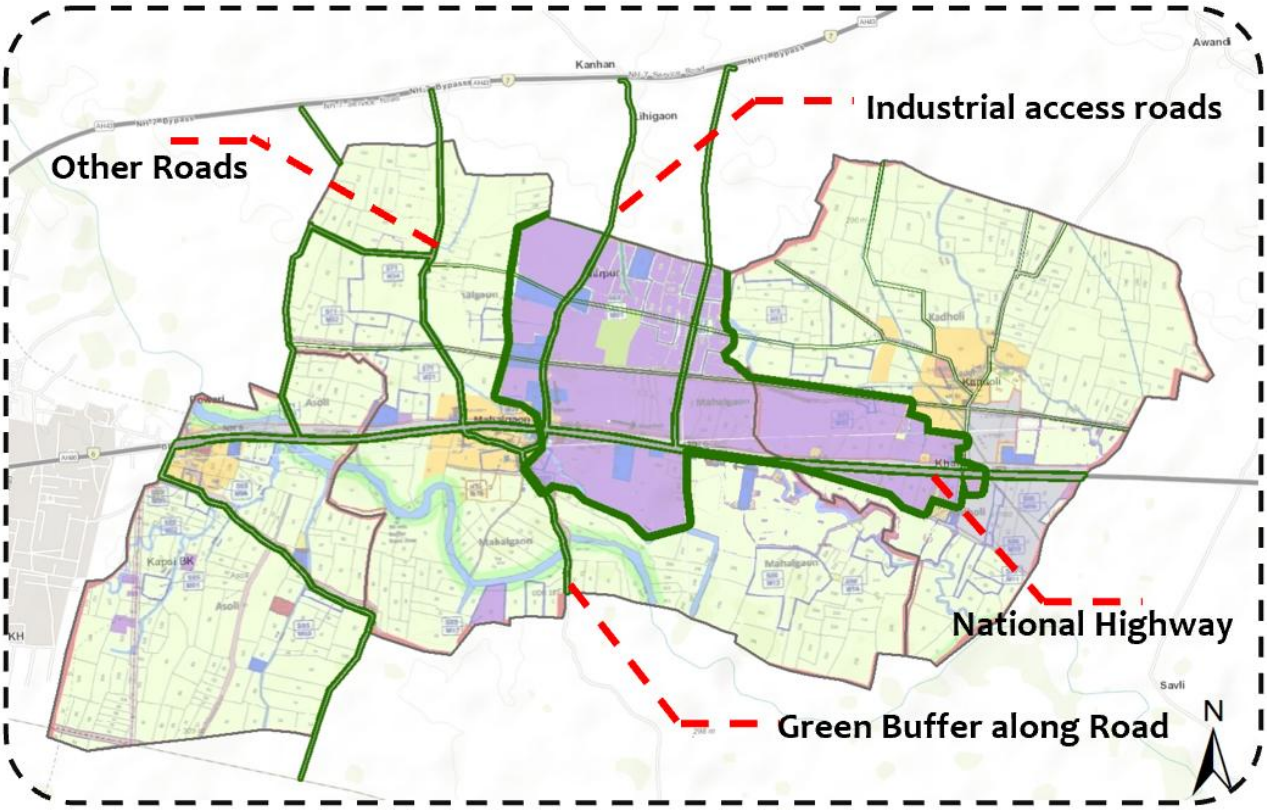


Figure 5.15 Green Buffer along Road and Indutrial Green Buffer

1. Green Buffer Development and its Carbon Sequestration Potential

To enhance environmental quality, pollution control, and carbon sequestration in the Mixed Cluster, green buffers have been proposed along key road typologies. The following summarizes the road-wise planning:

Table 5.15 Length and width of Green buffer along the road

Road Type	Length (m)	Buffer Width (m)	Total Buffer Area (m²)
Industrial Roads	2,508	30	2,508 × 30 = 75,240
National Highway	5,740	40	5,740 × 40 = 229,600
Other Roads	7,540	4 (2 m/side)	7,540 × 4 = 30,160
Total Area	—	—	**335,000 m² (33.5 ha)**

Recommended Buffer Widths by Road Type

Table 5.16 Road type and its width

Road Type	Recommended Width (One Side)	Source
National Highway	20–30 meters	As per IRC:SP:21 and URDPFI; pollution and noise barrier
State Highway	10–20 meters	CPCB and URDPFI recommendations
Major District Roads (MDR)	8–12 meters	Moderate buffer for farms and houses
Other District/Village Roads	3–6 meters	For dust, noise, microclimate control
Internal Village Streets	1.5–3 meters (if ROW allows)	Aesthetic greenery and hedges
Industrial Access Roads	15–25 meters	CPCB for red/orange industries
Roads near Waterbodies/Forests	30 meters (minimum)	MOEFCC and Forest Conservation norms

Table 5.17 Tree Count and Density Estimation

Road Type	Area (m²)	Area (ha)	Spacing	Density (trees/ha)	Tree Count
Industrial Roads	75,240	7.524	3 m × 3 m	1,111	~8,360
National Highway	229,600	22.96	3 m × 3 m	1,111	~25,500
Other Roads	30,160	3.016	4 m × 4 m	625	~1,885
Total	335,000	33.5 ha	—	—	**~35,745 trees**

Carbon Sequestration Potential

Using a scientifically accepted average of **30 kg CO_2/tree/year** (based on ICFRE, TERI, FAO studies), the estimated sequestration is as follows:

Table 5.18 Carbon Sequestration Potential of Green Buffer along Road

Metric	Value
Total Trees	35,745
CO_2 Sequestered/Tree/Year	30 kg
Total CO_2 Sequestered/Year	1,072,350 kg
In Tons	**~1,072.35 tons/year**

2. Biomass Estimation Methodology for Estimation Carbon Sequestration Potential of Industrial Green Buffer

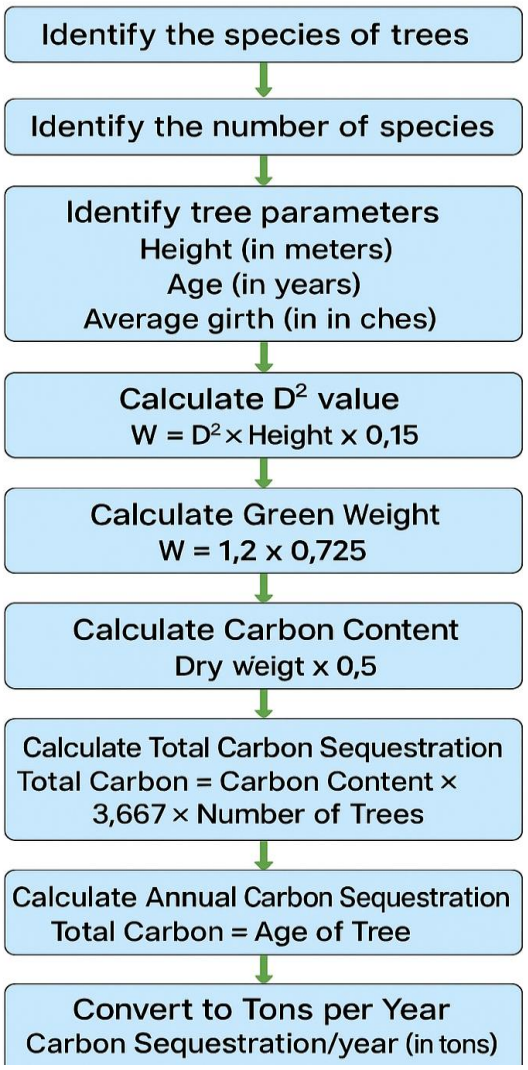

Identify the species of trees
Identify the number of species
Identify tree parameters
Height (in meters)
Age (in years)
Average girth (in in ches)
Calculate D² value
W = D² × Height x 0,15
Calculate Green Weight
W = 1,2 x 0,725
Calculate Carbon Content
Dry weigt x 0,5
Calculate Total Carbon Sequestration
Total Carbon = Carbon Content ×
3,667 × Number of Trees
Calculate Annual Carbon Sequestration
Total Carbon = Age of Tree
Convert to Tons per Year
Carbon Sequestration/year (in tons)

Figure 5.16 Biomass Estimatin Methodology

Table 5.19 Area Allocation – Based on Green Buffer Zoning of Industrial Area

Zone	Width (m)	Length (km)	Area (ha)	Purpose
Outer Zone	10	8	10 m × 8000 m = 8 ha	Native species for air & dust barrier
Middle Zone	30	8	30 m × 8000 m = 24 ha	Horticulture for income + carbon sink
Inner Zone	10	8	10 m × 8000 m = 8 ha	Timber/high biomass for long-term sink

Table 5.20 Tree Density Allocation - Based on Species Type and Land Use

Species Type	Typical Tree Spacing	Trees/ha	Application
Native Trees (Neem, Pongamia)	~4 m × 4 m	~600–700	Outer Zone (wind/dust buffers)
Bamboo (clumps)	~3 m × 3 m	~800–1000	Outer Zone (edge/buffer reinforcement)
Fruit Trees (Amla, Guava, etc.)	~3 × 4 m or 4 × 4 m	~800–900	Middle Zone (horticulture)
Timber Trees (Teak)	~4 × 4 m or 5 × 5 m	~600–700	Inner Zone (long rotation)
Melia dubia	~3 × 3 m	~1000	Inner Zone (fast-growing carbon species)

Table 5.21 Final Carbon Sequestration Table for Industrial Green Buffer

Species Name	Count	D^2	Avg Height (ft)	AGB (kg)	Green Weight (kg)	Dry Weight (kg)	Carbon Content (kg)	CO_2/ Tree/ Year (kg)	CO_2 Sequestered/Year (kg)	CO_2 Sequestered/ Year (Tons)
Neem *(Azadirachta indica)*	1,362	900	35	4,725.0	5,670.0	4,110.75	2,055.38	150	204,300	204.30
Pongamia *(Pongamia pinnata)*	1,362	900	35	4,725.0	5,670.0	4,110.75	2,055.38	150	204,300	204.30
Bamboo *(Bambusa bambos)*	1,947	625	30	2,812.5	3,375.0	2,446.88	1,223.44	200	389,400	389.40
Amla *(Phyllanthus emblica)*	3,499	400	25	1,500.0	1,800.0	1,305.00	652.50	120	419,880	419.88
Guava *(Psidium guajava)*	3,936	400	25	1,500.0	1,800.0	1,305.00	652.50	120	472,320	472.32
Drumstic *(Moringa oleifera)*	3,936	324	20	972.0	1,166.4	845.64	422.82	130	511,680	511.68
Custard Apple *(Annona S.)*	3,499	324	20	972.0	1,166.4	845.64	422.82	130	454,870	454.87
Teak *(Tectona grandis)*	2,609	900	35	3,281.25	3,937.5	2,953.13	1,427.34	140	367,380	367.38
Malabar Neem *(Melia dubia)*	2,609	625	35	3,281.25	3,937.5	2,854.69	1,427.34	250	652,850	652.85
GRAND TOTAL	**24,500**	—	—	—	—	—	—			3754.98

5.2.2 Soil Carbon Management Practices

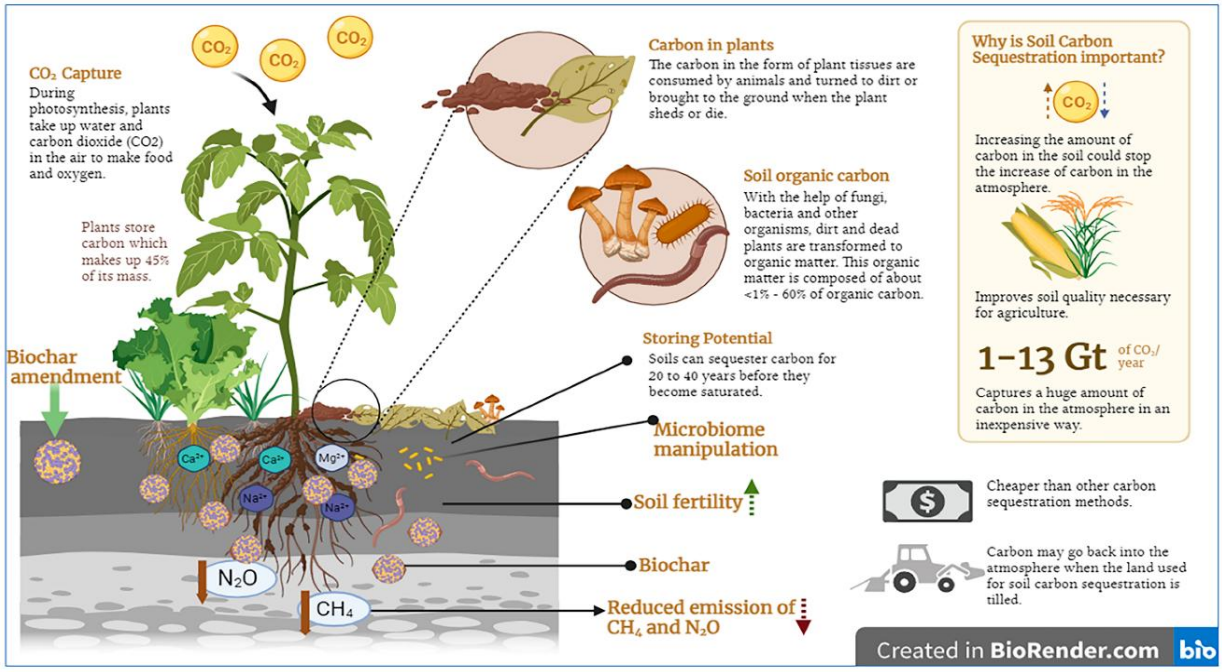

CO_2 Capture
During photosynthesis, plants take up water and carbon dioxide (CO2) in the air to make food and oxygen.
Plants store carbon which makes up 45% of its mass.
Biochar amendment
Carbon in plants
The carbon in the form of plant tissues are consumed by animals and turned to dirt or brought to the ground when the plant sheds or die.
Soil organic carbon
With the help of fungi, bacteria and other organisms, dirt and dead plants are transformed to organic matter. This organic matter is composed of about <1% - 60% of organic carbon.
Storing Potential
Soils can sequester carbon for 20 to 40 years before they become saturated.
Microbiome manipulation
Soil fertility
Biochar
Reduced emission of CH_4 and N_2O
N_2O
CH_4
Why is Soil Carbon Sequestration important?
Increasing the amount of carbon in the soil could stop the increase of carbon in the atmosphere.
Improves soil quality necessary for agriculture.
1-13 Gt of CO_2/year
Captures a huge amount of carbon in the atmosphere in an inexpensive way.
Cheaper than other carbon sequestration methods.
Carbon may go back into the atmosphere when the land used for soil carbon sequestration is tilled.
Created in BioRender.com

Figure 5.17 showing soil carbon management practices

In addition to afforestation and green buffers, the Kadoli–Asoli–Mahalgaon cluster integrates soil carbon practices and renewable energy-based interventions to enhance decarbonisation. Key interventions include:

Biochar application, Compost/Vermicompost use, Cover cropping & no-till, Biogas units and solar pumps. These techniques can increase soil carbon by 0.3 to 6 tCO_2e/ha/year and avoid methane emissions from traditional fuel or dung handling—resulting in multi-layered, scalable mitigation, with the ability to offset thousands of tons of CO_2e annually.

Table 5.22 Soil and Energy Based Interventions Table

Category	Technique	CO_2 Impact	Where to Implement
Soil-Based	Cover Cropping + No-Till	0.5–1.5 tCO_2e/ha/year	All cropland, orchards
Soil-Based	Biochar from Crop Waste	3–6 tCO_2e/ha/year	Organic farms, compost pits, bunds
Soil-Based	Compost/Vermicompost	0.3–0.6 tCO_2e/ha/year	All agricultural land
Energy-Based	Biogas from Dung (CH_4 Avoidance)	1.5–2 tCO_2e/plant/year	SHG or community biogas plants
Energy-Based	Solar Pumps for Irrigation	1–3 tCO_2e/ha/year	Groundwater-irrigated agricultural fields

Table 5.23 Policy Implementation Matrix

Component	Policy Action	Implementation Strategy
Cover Cropping + No-Till	MGNREGS + State Agri Schemes	₹300–500/ha/year + training via Krishi Vigyan Kendras (KVKs)
Composting	SHG-led compost units (crop/dung based)	Integrate with Panchayat waste plans via Rural Livelihood Missions
Biochar	Promote small-scale kilns via FPOs	50–70% subsidy + field bunds/orchard support
Biogas Units (CH_4 Avoid.)	Install for households, dairies, SHG clusters	Funded by MNRE Biogas Scheme; reuse slurry in composting
Solar Pumps for Irrigation	PM-KUSUM support expansion	Replace diesel pumps + integrate with agri-extension programs
Convergence & Monitoring	Integrate MGNREGS, PM-KUSUM, Biogas, Panchayat frameworks	Monitor via EX-ACT or Cool Farm Tool, and build local capacity

5.2.3 Intervention-Wise Carbon Sequestration Summary

Table 5.24 Intervention-Wise Carbon Sequestration Summary

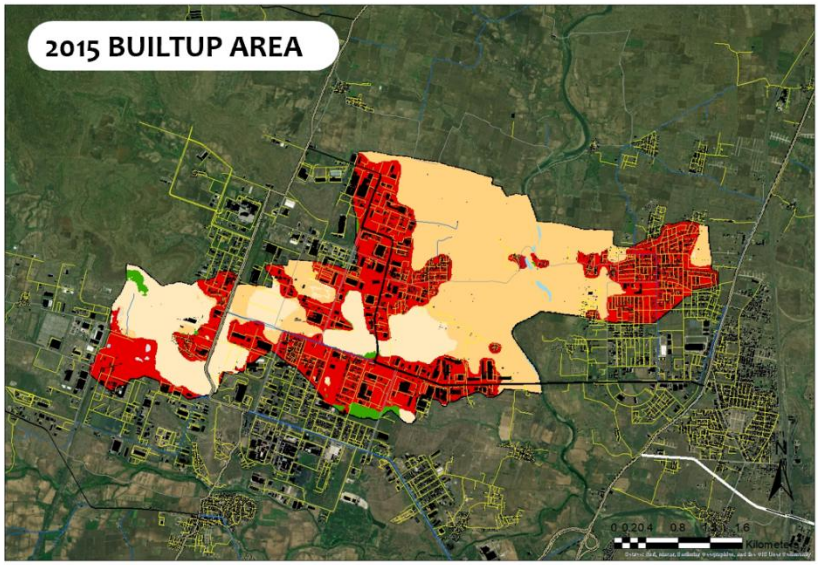
Intervention	Unit/Area Applied	Adoption Rate / Count	Emission Factor Used	Calculation Method	Estimated CO_2 Sequestered (tons/year)
1. Green Buffer along Roads	33.5 ha	35,745 trees	30 kg CO_2/tree/year	35,745 × 30 = 1,072,350 kg = 1,072.35 tons	1,072.35
2. Afforestation by Species Mix	Green zones	24,500 trees (mixed)	Avg. 153 kg CO_2/tree/year	Biomass formula-based	3,754.98
3. Soil Carbon Management (Cover + Compost)	816 ha of agriculture	60% land (≈490 ha)	1.5 tCO_2/ha/year	816 × 1.5 × 0.6 = 734.4 tons/year	734.40

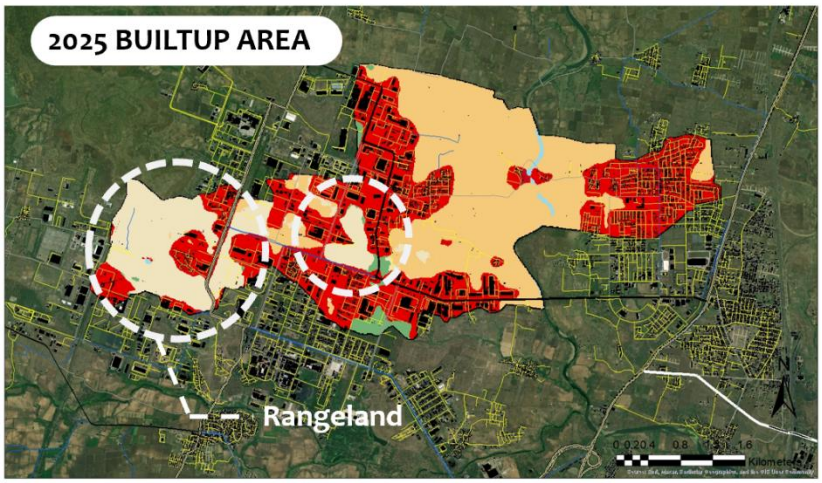
Intervention	Unit/Area Applied	Adoption Rate / Count	Emission Factor Used	Calculation Method	Estimated CO_2 Sequestered (tons/year)
4. Biochar from Crop Waste	816 ha eligible land	Full application	3 tCO_2e/ha/year	816 × 3 = 2,448 tons/year	2,448.00
5. Solar Pumps for Irrigation	816 ha irrigated land	Full coverage assumed	3 tCO_2e/ha/year (diesel displacement)	816 × 3 = 2,448 tons/year	2,448.00
TOTAL					**10,457 tons/year**

Category	Emissions / Sequestration	Value (tCO_2/year)
Scope 1 Emissions	Livestock, agri, mobility, etc.	21,396.17
Scope 2 Emissions	Electricity × 0.82 EF	2,688.72
Total Emissions	Scope 1 + Scope 2	24,084.89
Sequestration Potential	All strategies combined	~10,457
Net Offset Achieved	10,457.73 ÷ 24,084.89	~43% offset

Thematic Layer	Strategy (Mixed-Use Specific)	Phase	Scope Targeted	Justification for Mixed Cluster
Spatial Planning	Rooftop Solar on Public/SHG Buildings	Phase 1–2	Scope 2	Many SHG, health, school, and commercial rooftops exist due to land mix. Rooftop PVs reduce grid dependency and serve mixed land-use zones.
	Urban Agroforestry (fruit trees + native shrubs)	Phase 2	Carbon Sink, Scope 3	Land patches near institutions, streets, and edges of peri-urban zones allow fruit/nutritional plantations, enhancing carbon sequestration and urban ecology.
Financial Structuring	Carbon-linked Credit via SHG/Cluster Federations	Phase 2–3	Scope 1	Promotes pooled access to carbon credits via compost, agroforestry, or EV use. Mixed economies benefit from federated financial innovation.
	Rental Model for Solar Dryers and Agro-machinery	Phase 1–3	Scope 2, Scope 3	Mixed clusters need shared access to solar dryers, tillers, etc. SHG-led rental helps reduce emissions from diesel-based post-harvest operations.
Technological Tools	Community-Based Solid Waste Segregation + IoT Composting	Phase 1	Scope 1 (Waste), Governance	Mixed-use areas produce municipal + agri + food waste. IoT-based bins or smart composters enable waste valorization at source and minimize landfill load.
	Mobile Emissions Inventory App for Mixed Transport Use	Phase 2	Scope 1, Governance	Helps track emissions from autos, tractors, personal vehicles. Useful in mixed areas with varied transport modes. Panchayat can monitor via mobile app.
Urban–Rural Linkage	Compost/Organic Produce Kiosks at Village Junctions	Phase 2–3	Scope 3	Leverages footfall in peri-urban areas to sell local compost, bio-pesticides, or processed foods. Reduces transport and promotes circular economy.
	Urban Waste-to-Compost Barter with Local Markets	Phase 3	Scope 3	Urban traders offload biodegradable waste (fruit peels, etc.) to rural SHGs in exchange for compost/biogas. Reduces waste and encourages collaboration.
Policy Recommendation	EV Charging Zones near Gram Sabha Office/Public Market	Phase 1	Scope 2	Mixed-use villages have scope to become EV-ready nodes. Charging points for e-rickshaws/carts create an enabling environment for zero-carbon mobility and market connectivity.
	Mixed Land Zoning Policy with Carbon Limits	Phase 3	Scope 1 + Regulation	Develop zoning that sets emission benchmarks for residential, agricultural, and commercial subzones. Useful in mixed clusters with overlapping land uses and transitions.

5.3 Proposal for Industrial Cluster





A comparative analysis of the built-up area between 2015 and 2025 reveals the changing spatial dynamics of the designated industrial cluster. In 2015, development was relatively concentrated, but by 2025, built-up expansion has occurred in a more scattered pattern, particularly along the edges of the settlement. Despite the land being officially designated for industrial development, actual construction activity over the past decade has remained minimal. This has resulted in vast tracts of **rangeland and open/degraded land** remaining underutilized.

The proposed land use map indicates that the region has been earmarked as an **Industrial Cluster**, but a large proportion of this land remains undeveloped. This underdevelopment poses two key challenges: first, the **inefficient use of land resources** that could otherwise support planned industrial infrastructure, and second, the **risk of unregulated industrial sprawl** into ecologically or agriculturally sensitive areas.

Table 5.26 Feature rangeland and its carbon farming potential

Feature of Rangeland	Carbon Farming Potential
Open & underutilized	Available for **afforestation / agroforestry**
Low ecological value	Can be transformed into **carbon sinks**
Close to industries	Can be used as **offset zones** for emissions
Managed by Gram Panchayat	Easy to integrate via **DP & CSR** funding

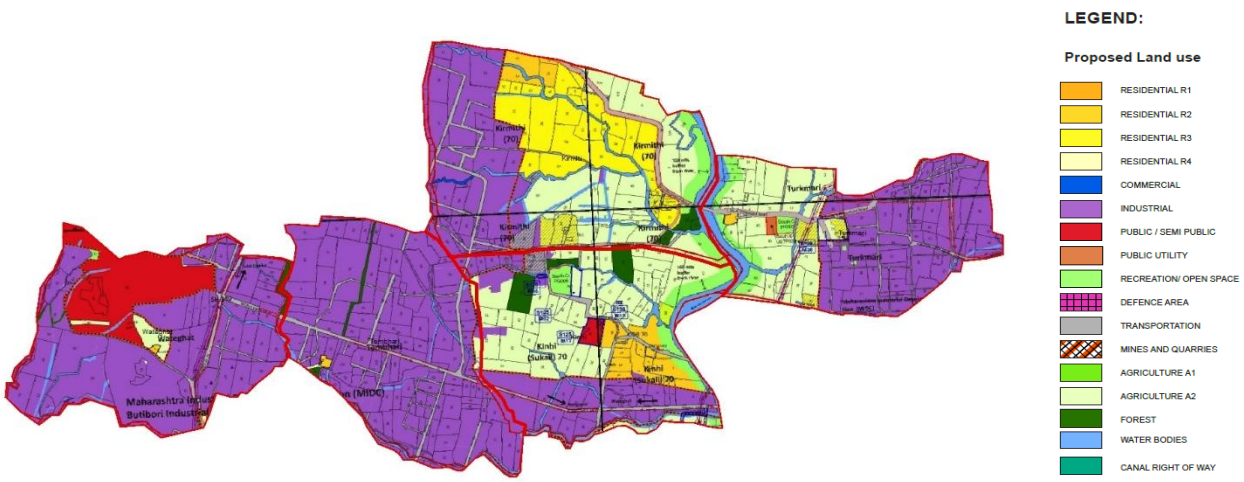


Figure 5.18 Proposed landuse in Development Plan

5.3.1 Carbon Offset Plantation Strategy on Rangeland for Industrial Emissions Mitigation

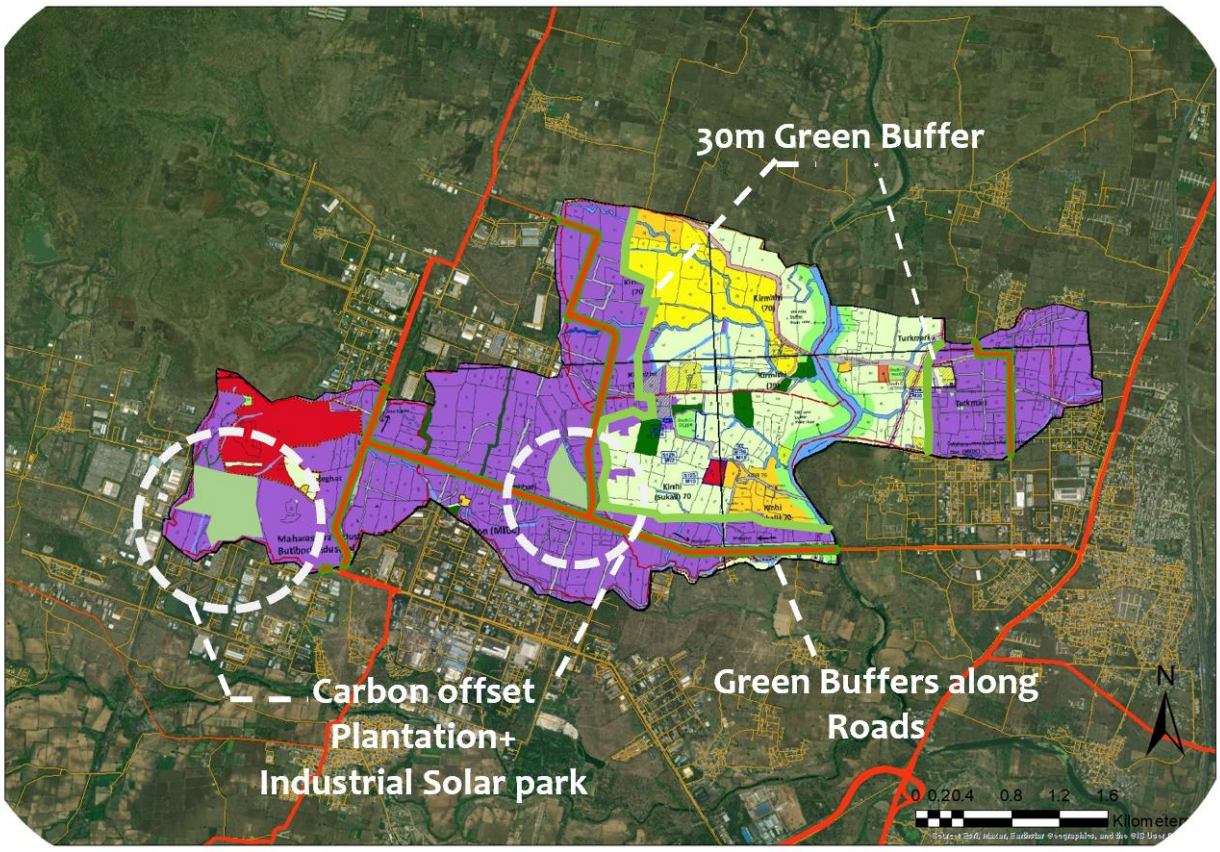


Figure 5.19 Proposed Interventions for Industrial Cluster

In light of the proposed industrial expansion within the Development Plan (DP) area, significant GHG emissions are anticipated from both direct and indirect sources (Scope 1 and Scope 3). To mitigate this impact, a combined land-use and renewable energy strategy has been proposed. This includes the integration of **Carbon Offset Plantations**, **Green Buffer Zones**, and **Industrial Solar Parks** within the industrial cluster boundaries.

- **Problem**: The planned industries are expected to generate high Scope 1 (fuel combustion, process emissions) and Scope 3 (supply chain) emissions.
- **Opportunity**: A substantial amount of **rangeland** exists within the village boundary, especially near industrial zones. This land is underutilized, ecologically degraded, and currently unmanaged.
- **Solution**: These rangelands can be repurposed as **carbon farming zones**, supporting afforestation and agroforestry activities. In combination with **green buffers** and **solar infrastructure**, they can act as **carbon sinks** and enable the generation of **carbon credits** under compliance and voluntary carbon markets.

Table 5.27 Proposed Interventions for Industrial Cluster

Strategy	Land Use Target	Key Benefits	Scope Impacted
Carbon Offset Plantation	Degraded rangeland near industry	CO_2 sequestration, carbon credit	Scope 1 (offset), Scope 3
Green Buffer Zones	Around Red/Orange industries	Pollution control, microclimate	Scope 1
2. Industrial Solar Parks	Rangeland edges, grazing lands	Enables smaller units to switch from MSEDCL/DISCOM to RE	Scope 2

Table 5.28 Carbon Sequestration Potential of Key Interventions

Strategy	Mechanism	Area Type	Carbon Benefit (per ha/year)	Scope	Source
1. Carbon Offset Plantation	Fast-growing native trees (e.g., pongamia, bamboo) on degraded rangelands	Rangeland (wasteland)	**3–7 tCO_2/ha/year**	Scope 1 (sink), Scope 3	IPCC AFOLU, WRI India, UNCCD agroforestry data
2. Green Buffer Zones	Pollution-tolerant trees for dust, heat, noise mitigation	Industrial boundary	**1.5–3 tCO_2/ha/year**	Scope 1 (pollution control)	CPCB + URDPFI guidelines for green buffering
3. Industrial Solar Parks	Offsets electricity from fossil-grid (MSEDCL) by solar generation	Grazing/rangeland	**6–8 tCO_2/ha/year**	Scope 2 (electricity avoided)	IREDA, MNRE benchmarks: 1 MW solar ≈ 1.5 ha ≈ 1450 tCO_2/year

Table 5.29 Phase wise Decarbonizing Strategies for Industrial Cluster

Thematic Layer	Strategy	Detailed Justification	Phase	Scope Targeted
Spatial Planning	Green Buffer Zones (30–50m)	Establish native plantations (e.g., bamboo, pongamia) between industrial and residential/agri zones. Aligned with **CPCB 2019 buffer norms** and **URDPFI 2015** zoning principles. Helps mitigate **PM, SOx, NOx**, reduces urban heat effect, and protects community health.	Phase 1	Scope 1, 3
Financial Structuring	CSR-Based Afforestation	Utilize **CSR funds** (Companies Act Sec. 135) to develop green zones on rangelands. Supports **ESG goals**, enhances local carbon sink potential, and avoids land-use conflict. Fits well with fast-growing, high CO_2 absorbing species like **pongamia** and **bamboo**.	Phase 2	Carbon Offset (Sink)
Technological Tools	Pollution Dashboards (IoT + Digital Monitoring)	Install IoT sensors to track PM, SO_2, NO_2 and electricity usage. Stream data to MIDC/GP-controlled dashboard. Supports **IPCC Tier 1 GHG tracking**, enables transparent reporting, real-time mitigation, and public participation.	Phase 1–3	Scope 1, 2
	Industrial Solar Parks / Rooftop Solarization	Install shared solar parks or rooftop PV systems for MSMEs and industrial units. Supports **National Solar Mission**, reduces **Scope 2** emissions, and aligns with **SECI/IREDA funding** and **Companies Act ESG mandates**. Ideal for MIDC areas with high energy demand and daytime industrial operations.	Phase 2	Scope 2
Urban–Rural Linkage	Electrified Labor & Logistics Transit	Develop EV-based shuttles and freight for industrial labor and cargo from nearby villages. Backed by **PM-eBus Seva (2023)** and **URDPFI clean mobility** guidance. Reduces fuel use, improves worker welfare, and cuts **Scope 3** emissions related to transport.	Phase 2–3	Scope 3
Policy-Level Recommendation	Mandate ESG Compliance via GP Notification	Pass a **Gram Sabha resolution** requiring green buffers, pollution dashboards, and ESG disclosures as conditions for local NOC issuance. Integrates **Companies Act Sec. 134 & 135**, **CPCB buffer enforcement**, and SPCB's **CTO system**, giving Panchayat legal oversight on industrial compliance.	Phase 1–3	Scope 1, 2, 3 + Governance

Chapter -6
IMPLEMENTATION CHALLENGES

Table 6.1 Implementation Challenges for Agrarian Cluster

Cluster	Proposal / Intervention	Key Challenges	Remarks
Agrarian(Tarsa–Nawegaon–Ashti)	Agrivoltaics (Scope 2 Offset)	High capital cost- Difficulty integrating solar in fragmented landholdings. Farmer hesitation due to crop shade concerns	Needs PM-KUSUM support + demo projects; potential on village-owned or community lands
	AWD (Alternate Wetting & Drying)	Irrigation habits hard to change- Requires field-level monitoring-Groundwater availability variation	Effective only with training + scheduling; best implemented with SHG or KVK support
	Biochar Application	Lack of pyrolysis equipment - No awareness of biochar benefits- No market or registry linkage	Common in pilot projects but not scaled in rural Maharashtra; community-level production can help

Table 6.2 Implementation Challenges for Mixed Cluster

Cluster	Proposal / Intervention	Key Challenges	Remarks
Mixed (Kadoli-Asoli-Mahalgaon)	Agrivoltaics / Rooftop Solar	Limited awareness- High upfront cost- O&M difficulties in decentralized systems	Rooftop or cooperative solar models are feasible if supported under PM-KUSUM or local RE schemes
	Bund Plantation + Composting	Small or fragmented land parcels- Seasonal residue supply- Labour shortages	Effective in watershed/ contour farming areas; SHG-based composting support through NRLM recommended
	Green Buffer Zoning	Enforcing buffer zones is difficult on private land- Resistance from growing residential areas	Requires Gram Panchayat-level regulation, inclusion in local DCR, and support from land-use zoning maps
	Biogas Units (Decentralized)	Uneven livestock density- High setup + maintenance costs- Low dung availability in dry seasons	SHG or cooperative-led mini-biogas clusters are more feasible than individual setups

Table 6.3 Implementation Challenges for Industrial Cluster

Cluster	Proposal / Intervention	Key Challenges	Remarks
Industrial (Turkmari-kinhi-Tembhari-Wateghat-Kirmiti)	Green Buffers (as per CPCB/URDPFI)	Land encroachment- Poor enforcement by industrial bodies- Land acquisition delays	Can be enforced with zoning-based approvals; needs monitoring + support from MIDC/Gram Panchayat
	Carbon Farming (on rangelands)	No clear land titles- No revenue unless linked with carbon credits- Lack of plantation incentive	Mapping of degraded/range land required; can link with CSR for fast-growing native tree plantations
	Composting of Organic Waste	Waste segregation absent- No centralized treatment system- Industries may not comply	Can be enabled via common composting facilities with support from MIDC/PCB
	Solar Park / Industrial RE Shift	Expensive- Grid connectivity limitations- Long payback periods	Requires MIDC land + DISCOM cooperation; viable under PPP with carbon credit stacking

Chapter -7
CONCLUSION AND DISCUSSION

This study formulates an integrated and typology-specific framework for rural decarbonisation by combining scientific greenhouse gas (GHG) estimation techniques with spatial and policy-based planning tools. Representative villages were selected from three distinct rural typologies—agrarian, mixed-use, and industrial—within the Nagpur Metropolitan Region to capture the diversity of emission sources and land-use patterns. Emissions were quantified using the IPCC Tier 1 methodology, applying sector-wise Scope 1, Scope 2, and Scope 3 classifications. These estimations were supported by primary household and industrial surveys, secondary datasets, and geospatial analysis, allowing for a detailed assessment of carbon-intensive activities and spatial land-use conflicts. The methodological approach enabled the identification of both emission hotspots and opportunities for targeted decarbonisation interventions within each typology.

The results indicate clear spatial and functional variations in emission profiles across the three typologies: agrarian villages predominantly emit methane from flooded rice fields and enteric fermentation; mixed-use villages experience diffuse emissions across transport, domestic energy, and agriculture; while industrial clusters exhibit concentrated emissions due to unregulated combustion, underutilised land, and proximity to high-risk industrial processes. The study further reveals a mismatch between designated land use and actual development, particularly in industrial zones, contributing to inefficient resource use and increased emissions risk.

In response, the thesis proposes typology-specific decarbonisation strategies such as alternate wetting and drying (AWD) with solar irrigation, agrivoltaic systems, carbon offset plantations on degraded rangelands, green buffer zoning, and the deployment of industrial solar parks. These interventions are aligned with the UN-Habitat's Net Zero Village Planning framework and India's Nationally Determined Contributions (NDCs), and are structured to be implementable through local planning instruments and funding mechanisms such as Development Plans (DPs), GPDPs, and CSR initiatives.

Overall, this study demonstrates the potential for rural settlements to serve as effective agents of climate action through integrated land use and carbon planning. It establishes a replicable and scalable model for low-carbon rural development, contributing to India's long-term climate goals while enhancing ecological resilience, community well-being, and sustainable rural livelihoods.

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